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1996 National Technical Report on Forest Health

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Abstract

Forest Health Monitoring (FHM) is a national program designed to determine the status, changes, and trends in indicators of forest condition on an annual basis. The FHM program uses data from ground plots and surveys, aerial surveys, and other biotic and abiotic data sources and develops analytical approaches to address forest health issues that affect the sustainability of forest ecosystems. This report focuses on 18 States that have survey and ground plots. Six forest health issues were identified by the FHM program in 1996 to evaluate forest health: forest ecosystem fragmentation, forest vitality, key ecosystem processes, plant biodiversity, soil conservation, and wildlife habitat. This report identifies data needs, analytical approaches, and spatial patterns of indicators to address these forest health issues. Based on current analysis, forest ecosystems in 18 States are stressed to various degrees by urbanization, air pollution, exotic plant species, native and exotic insects and diseases, and climate- and weather-related events. These stressors are more severe in some areas of the country than others, and their influence on forest health is apparent. In general, the forests in these 18 States are in relatively good health.

Keywords: Damage, exotic vegetation, forest health, indicators, insects and disease, monitoring, sustainability.

Forest Resource

Approximately 1.7 billion acres of the United States (about 67 percent of the total area) are classified as forest, rangeland, or water of which approximately 0.8 billion acres are forested lands[1]. About 33 percent of the forested lands are in Federal ownership. The amount of forested land in the United States was reduced during early European colonization by converting forest to farmland, by wildfire, and by using wood for fuel, fences, railroad ties, and other products (MacCleery 1992). By the early 1900's, tens of millions of acres of forest had been cut. However, the general decline stabilized, and many aspects of forest ecosystems improved including increased timber production, increased wildlife, reduced soil erosion, reduced flooding, and reduced catastrophic wildfires (MacCleery 1992).

Progress in improving and maintaining the health and sustainability of forest ecosystems in the last century is under constant threat because human demands on our forests are increasing. The ability of forests to maintain a balance of successional stages through natural disturbances has been reduced, and the diversity of forests has been affected (see footnote 1). Monitoring forest ecosystems is essential to evaluating the condition of forest resources, changes in their condition, and significant trends in natural forest cycles that are outside expected ranges.

[1] U.S. Department of Agriculture, Forest Service. 1995. The Forest Service program for forest and rangeland resources: a long-term strategic plan. [Published draft 1995 Resources Planning Act Program.] On file with: Programs and Legislation Deputy Chief, U.S. Department of Agriculture, Forest Service, Washington, DC. 177 p.

Forest ecosystems cover over 30 percent of the United States and provide important recreational opportunities, wildlife habitat, aesthetic benefits, timber products, and watershed integrity. Impacts from native and exotic pests, air pollution, past management practices (including fire suppression), and climate change are some of the primary stressors that concern the public as well as the land managers who are responsible for maintaining the long-term vitality of the Nation's forest ecosystems.

Forest Health

Kolb and others (1994) considered a forest ecosystem to be healthy or sustainable if it possessed the following attributes:

- The physical environment, biotic resources, and trophic networks needed to support productive forests in at least some seral stages.
- Resistance to dramatic changes in population or key organisms within the ecosystem beyond that expected for successional trends.
- A functional equilibrium between supply and demand of essential resources, such as water, nutrients, light, and space, for most of the vegetation components.
- A diversity of seral stages, cover types, and stand structures that provide habitat for many native species and a framework for all essential ecosystem processes.

Rapport and others (1985) have delineated several components or processes of both terrestrial and aquatic ecosystems that are often affected when stressors are severe or occur with a frequency beyond historic variations. These components and processes are: nonhistoric positive or negative variances in nutrient pools, primary productivity, size distributions, species diversity, and successional retrograde (return to an earlier successional stage).

Scientists may never completely agree on how to define the health of forest ecosystems, how to measure it completely, or how to interpret the measurements made. But, forest health remains an important national and global concern because part of the economic and social needs for all nations can only be met now and in the future through sound ecological management of forest resources. The U.S. Department of Agriculture (USDA) Forest Service strives to manage national forest resources in a sustainable manner to ensure that current and future generations will be able to use and enjoy the benefits of healthy forests. The health of forest ecosystems is of paramount importance to the USDA Forest Service, and several deputy areas within the agency have specific programs that research, inventory, or monitor forest health. These deputy areas, and their respective programs, are State and Private Forestry (Forest Health Protection), Research and Development (Long-Term Ecological Research and Forest Inventory and

Analysis), and National Forest System (Current Vegetation Inventory and Survey).

The health of a forest ecosystem can be evaluated using current measurements of key ecosystem processes and components in the context of their expected or historical variability. Based on research and monitoring in laboratory settings and on experimental forest sites, and by evaluating declining forest ecosystems, key components and processes known to contribute to forest health can be more clearly identified. Participants in multinational workshops use these key components to develop central criteria to evaluate the sustainability of forest ecosystems. For example, the multiple workshops of the Montreal Process produced the Santiago Declaration (Anon. 1995), which defines ecological, socioeconomic, and institutional criteria and indicators for the sustainable management of forest ecosystems. Table 1 depicts the ecological criteria set forth in that Declaration.

Table 1—Ecological criteria and indicators for the sustainable management of forest ecosystems

Santiago Declaration			
Criterion	Indicator	Measurement	FHM Program
Biological diversity:			
Ecosystem diversity	Areal extent of forest types	Percent total forest Percent nonprotected[a] Percent protected[a]	***
	Fragmentation of forest types		*
Species diversity	Forest-dependent species	Total number[b] Status of risk species[c]	**
Genetic diversity	Proportion of former range		
	Population levels of representative species[d]		
Productive capacity	Timber production[e]		***
	Total growing stock[f]	Plantations[g] Annual removal wood products[h]	***
Ecosystem health and vitality[i]	Insects and disease		***
	Competition from exotics		**
	Abiotic stressors	Fire Storms Flooding Salination	*** *** *** ***
	Management/use	Land clearance Domestic animals	***
	Air pollutants	S, N, O_3, etc. UV-B	**
	Biological indicators of key processes[j]	Epiphytes Insects Fauna Vegetation Communities	** ** **

Table 1—Ecological criteria and indicators for the sustainable management of forest ecosystems (continued)

	Santiago Declaration		
Criterion	Indicator	Measurement	FHM Program
Soil resource[k]	Physical properties	Erosion	**
		Compaction	*
		Other physical properties	**
	Chemical properties	Organic matter	**
		Nutrients	**
		Toxins	**
	Protective functions[l]		
Water resources[m]	Stream flow and timing		
	Biological diversity		
	Physical properties	Temperature	
		Sediments	
	Chemical properties	pH	
		Dissolved oxygen	
		Electrical conductivity	
Global carbon cycles[n]	Total ecosystem biomass/carbon pool[o]		**
	Sequestration/release of carbon	Standing biomass	**
		Coarse woody debris	
		Peat	
		Soils	**
	Forest products		

* = Techniques for measurement or estimation under development in the FHM Program.

** = Techniques for measurement or estimation developed by the FHM Program and implemented regionally.

*** = Techniques for measurement or estimation developed by the FHM Program and implemented nationally in 18 States.

[a] By forest types and age class.

[b] Number of forest-dependent species.

[c] Number of breeding populations.

[d] Species/diverse habitat/total range.

[e] Area and net area available; population estimate is coarser than those obtained by FIA.

[f] Merchant and nonmerchant available.

[g] Area/growing stock, native and exotic species.

[h] Compared to sustainable volume.

[i] Based on area and percent forest affected.

[j] Nutrient cycling, reproduction, etc.

[k] Based on area and/or percent.

[l] Watersheds, floods, avalanche, riparian.

[m] Based on historical patterns.

[n] Contribution of forests.

[o] e.g., forest type, age class, etc.

Forest Health Monitoring Program

Monitoring systems to evaluate forest health should provide information to landowners and managers about the ecological status of forests, what changes are occurring, the causal agents of these changes, whether changes indicate a trend, the expected outcome if trends continue, and the effect of management decisions on existing conditions. To enable landowners and managers to manage forest ecosystems in a sustainable manner, spatially and temporally intensive monitoring systems and regionally based monitoring regimes are essential. In addition, the socioeconomic benefits of healthy forests and the legal, institutional, and economic infrastructure required to support the ecological and socioeconomic monitoring data must be considered part of sustainable forest management.

Intensive monitoring systems identify key structure and function of forest ecosystems, how these key components work, what can be expected from perturbations, what indicators are important to evaluate, and how to interpret data from indicators. Evaluation of forest ecosystems can be done on a regional basis by considering data collected from ground plots, ground and aerially sensed surveys, and satellite monitoring of entire landscapes. Relevant indicators on ground plots detect subtle, extensive changes in the forest ecosystem. Ground and aerial surveys are used to detect more random, obvious changes and to evaluate small changes in forest extent and forest fragmentation. Satellite monitoring provides expanded coverage of greater changes in forest extent and fragmentation and how forests relate spatially with other terrestrial and aquatic ecosystems.

The Forest Health Monitoring (FHM) program is a multiagency, cooperative effort to determine the status, changes, and trends in all forest ecosystems in the United States (Forest Health Monitoring 1994b) on an annual basis. The partners in the FHM program include the USDA Forest Service (State and Private Forestry, Research, and the National Forest System), State Foresters, the U.S. Department of the Interior's Bureau of Land Management, and the U.S. Environmental Protection Agency. In partnership with States and the Bureau of Land Management, the USDA Forest Service directs the FHM program. The FHM program is designed to evaluate the condition, changes and trends in all U.S. forests on an annual basis, to evaluate the causes of poor forest condition and to evaluate key ecosystem components and processes to better understand how forest ecosystems function. The FHM program will help the United States and other participating countries address forest sustainability because the indicators used in FHM regional monitoring are based on productivity, diversity, vitality, soil conservation, and carbon sequestration.

In the FHM program, forest ecosystems are considered relatively healthy or sustainable, from an ecological perspective, if they meet specific criteria:

- Productive for wood, fruits, and other commodities,
- Biologically and structurally diverse,
- Large and not overly fragmented,
- Low in rates of anthropogenic contamination,
- Relatively balanced in distribution of age classes,
- Relatively free from invasion of exotic species,
- Resilient to natural stressors such as native pests, pathogens, and storms,
- Stable in chemical, biological, and physical soil processes,
- Sufficient in quality and quantity of water systems, and
- Relatively stable in carbon cycling.

The historic range of values for these attributes, which provides the context for interpretation of current values, differs among forests in different ecoregions. To evaluate whether these basic criteria are responding to natural and human-caused stressors in a sustainable or nonsustainable manner, FHM program scientists are considering guidelines by Kolb and others (1994) for sustainability and Rapport and others (1985) for nonsustainability (fig. 1).

The FHM program complements current monitoring programs that collect and analyze data so that land managers can make informed decisions (Lund and others, in press). To monitor forest resources on a national scale, a population-based sampling grid, with fixed-area plots approximately 27 kilometers (17 miles) apart, has been established in forest ecosystems throughout the United States (fig. 2). Each plot is sampled on four fixed-area subplots {each 168 meters $(m)^2$ [201 $yards^2$]}.

As of May 1995, the FHM program was established in 18 States (fig. 3) and partially established in Pennsylvania (not addressed in this report). The coarse nature of the FHM grid was initially designed to address forest health at an ecoregion province level (fig. 4) (Bailey 1995). Using multiple-year spatial analysis of rotating panel sampling with overlap will allow detection of relatively small changes in indicators at relatively small spatial scales, such as ecoregion sections greater than 2 million acres (Smith and others 1996), at a lower cost than sampling every plot every year.

Because the FHM program is implemented State-by-State, analysis of ecoregion provinces and sections will be most meaningful when all States are included. Currently, large sections of many ecoregions are not sampled (fig. 4). In this report, spatial patterns of indicators are evaluated by State to reflect the current status of indicators in the FHM program.

The FHM program can supply the public, academia, land managers, and industry with annual information that will help them perform risk assessments related to the

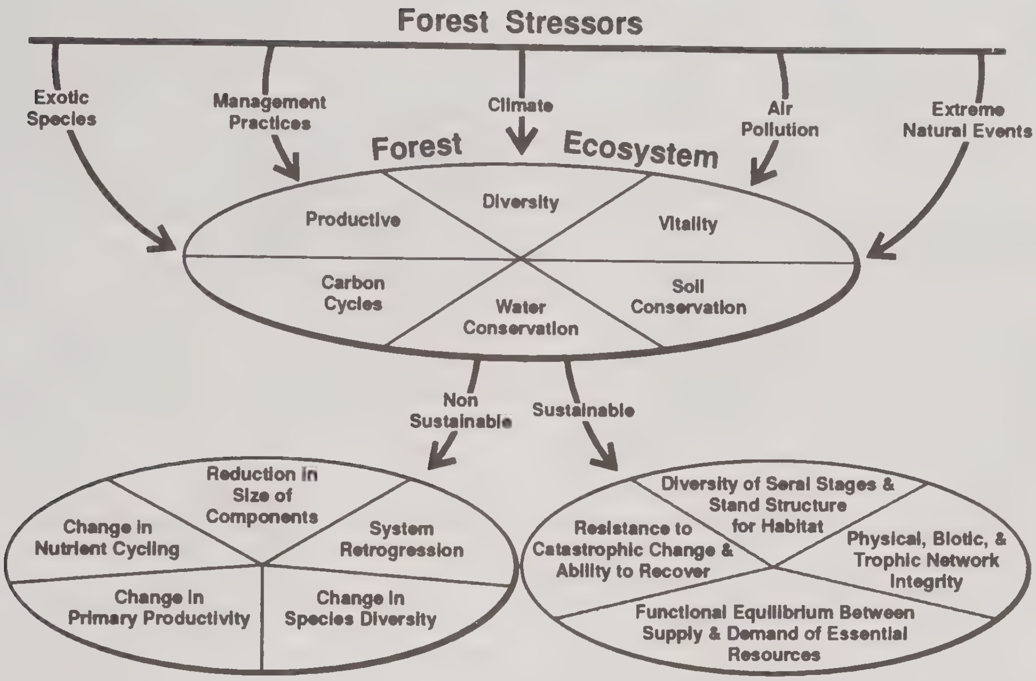

Figure 1—Evaluating the interactions among forest stressors, ecological criteria, and forest health sustainability.

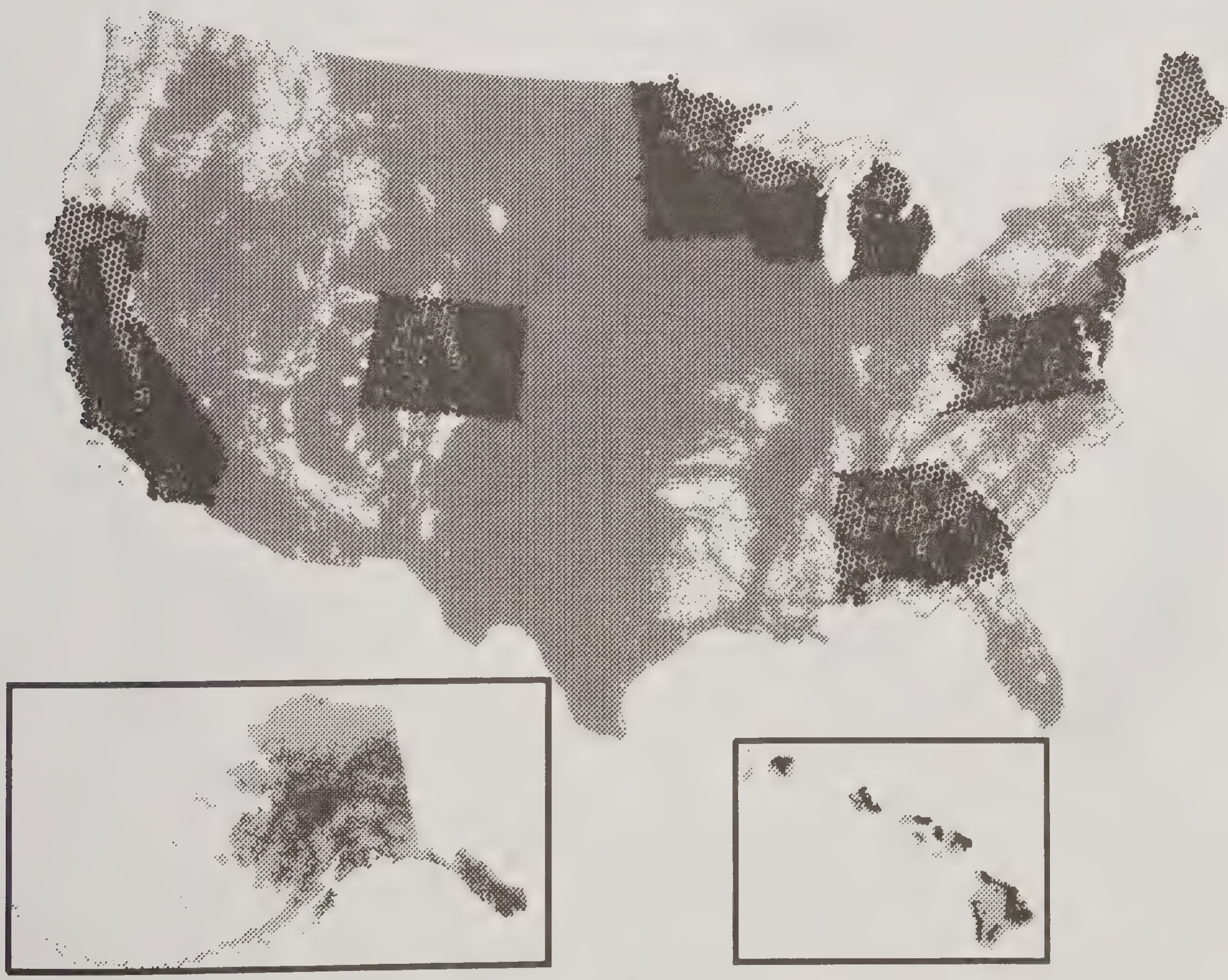

Figure 2—The spatial distribution of forests in the contiguous 48 States (white shading) and the Forest Health Monitoring sampling grid for the Plot Component of Detection Monitoring in 18 States. The distribution of forests in Alaska and Hawaii are also shown (black shading), but no Forest Health Monitoring Detection Monitoring is currently in place.

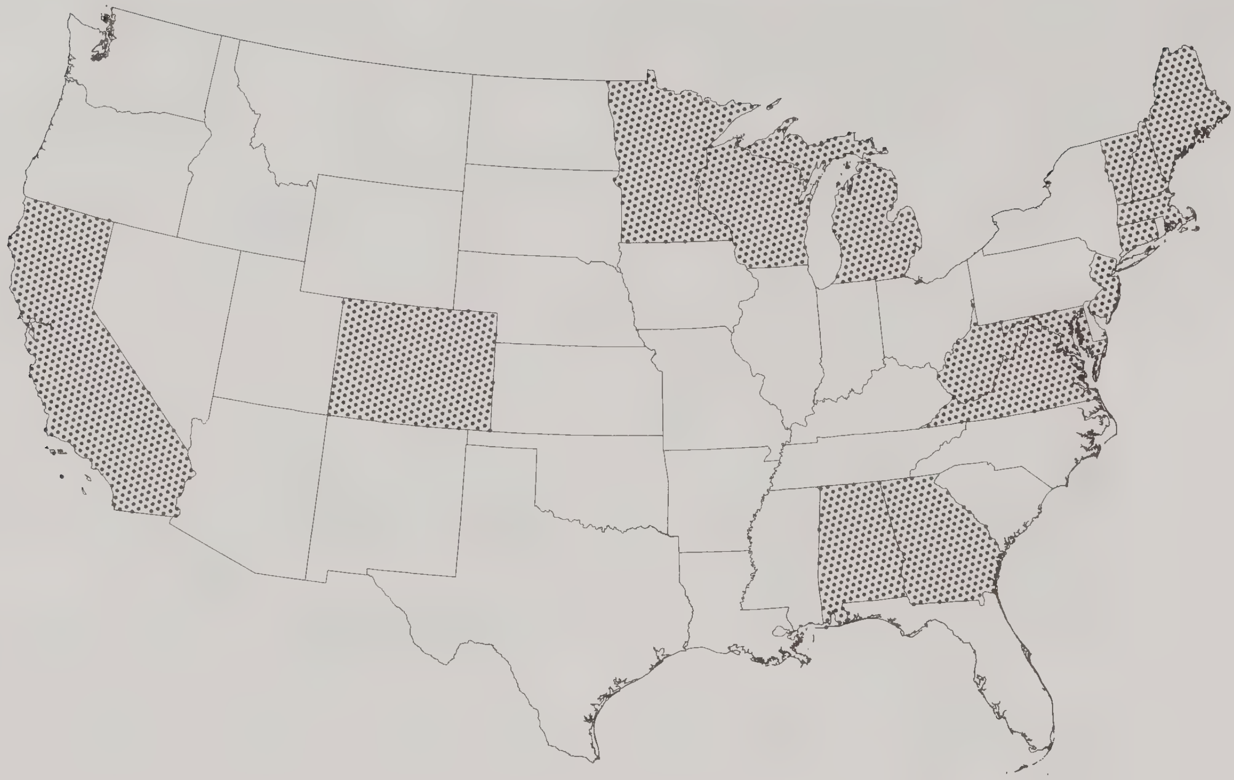

Figure 3—Forest Health Monitoring sampling grid for the Plot Component of Detection Monitoring in 18 States.

Figure 4—Ecoregion provinces overlaid with the Forest Health Monitoring sampling grid for the Plot Component of Detection Monitoring in 18 States.

sustainability of major forest ecosystems. Standardized nationally and internationally, the FHM program has a detailed quality assurance/quality control program, an intricate information management system, and data analysis procedures that can generate population estimates with confidence bounds. These population estimates will improve as the FHM program and the Forest Inventory and Analysis (FIA) program, with its more dense sampling intensity, become more complementary in the future. With approximately 4,000 forested plots in the 48 contiguous States, FHM data, combined with other inventory and monitoring programs, are at the appropriate scale to report on regional and national forest health issues.

The Report

The FHM program has four major components:

- Detection Monitoring (national or regional monitoring),
- Evaluation Monitoring (intensified monitoring or analysis in problem areas),
- Intensive Site Ecosystem Monitoring (monitoring to understand processes and improve predictive capabilities), and
- Research on Monitoring Techniques (research to improve monitoring techniques).

This report focuses on plot and survey approaches to national Detection Monitoring. It identifies the major regional forest health issues relevant to land managers, policymakers, and the public and presents a few conceptual and analytical approaches to address those issues. The spatial patterns of condition of some FHM Plot and Survey Component indicators related to the issues are evaluated to establish baseline or reference conditions for future trend analyses. Changes or trends in ecosystem condition will be reported after program stakeholders reach consensus on defining the current, most important issues.

This report is a first step to providing annual analysis of, and reporting on, forest health issues at a national scale—issues that are important to States, USDA Forest Service regions, and the USDA Forest Service national office in Washington, DC. It is part of a process that provides information coordination and sharing among the State, regional, and national components of the FHM program. It also contains the most information of national-level reports and is shown as the base of the reporting triangle for the national level (fig. 5). Requirements for FHM reporting were directed by officials in the USDA Forest Service Washington Office and are shown in the Forest Health Reporting Framework (fig. 5) (FS Memo May 24, 1996; file code 3400). This first report includes topics, particularly crown assessments, insects and diseases, and ozone air pollution, which are presented in the FHM northeastern report (USDA Forest Service 1995) and southern report (Hoffard and others 1995). Future reports may include information from other data sources, such as the USDA Forest Service's FIA, the Natural Resources Conservation Service's Natural Resource Inventory, the National Oceanic and Atmospheric Administration (climate), the U.S. Environmental Protection Agency (air pollution), and the U.S. Fish and Wildlife Service (fauna), to complete the base information needs for national-level reporting.

In general, this report describes three strategies to demonstrate methodology: (1) the analytical approach that focuses on how FHM data will contribute to the analysis, although no analysis of data is presented here; (2) regionally limited spatial displays of plot-level averages within States, or political or ecological units; and (3) spatial evaluations covering the 18 States currently in the Detection Monitoring component of FHM. Analyses use FHM data collected from 1992 through 1995 in California and Colorado, and primarily 1995 data from the eastern States. This dichotomy in analysis of yearly data between the West and East reflects the testing of two different sampling approaches: in the East, every plot was sampled every year, and, in the West, 25 percent of the plots were sampled each year, spatially covering the entire sample population each year. Thus, to present the most plot-level data on the condition of resources at the most sites in the West, multiple-year data were used.

Not an assessment of forest health, this report identifies and evaluates important criteria and indicators, current forest health issues, and indicators that are useful in evaluating issues. It addresses six major issues: forest fragmentation, forest vitality (tree condition, insects and disease, exotic plants, fire, and air pollution), important ecosystem processes (oak regeneration), biodiversity of plant species, soil conservation, and wildlife habitat.

Forest Health Issues

Fragmentation of Forest Ecosystems

Rapid expansion of urban development in, and adjacent to, forests, called the wildland/urban interface, increases the potential for fragmented forest ecosystems and presents serious problems to natural resource managers, urban planners, and conventional government policies and services (see footnote 1). Urban expansion increases the risk of wildfires, disruption of established animal populations, and injury to people, homes, and businesses. Inherent in this expansion is a general increase in the need to protect water quality, wildlife, and forest health while attempting to meet the social and recreational needs of people and provide for public health and safety.

On each of the four subplots in each FHM plot, the proportions of the subplot in distinctly different land-use classes are quantified (Bechtold and others 1995). One of

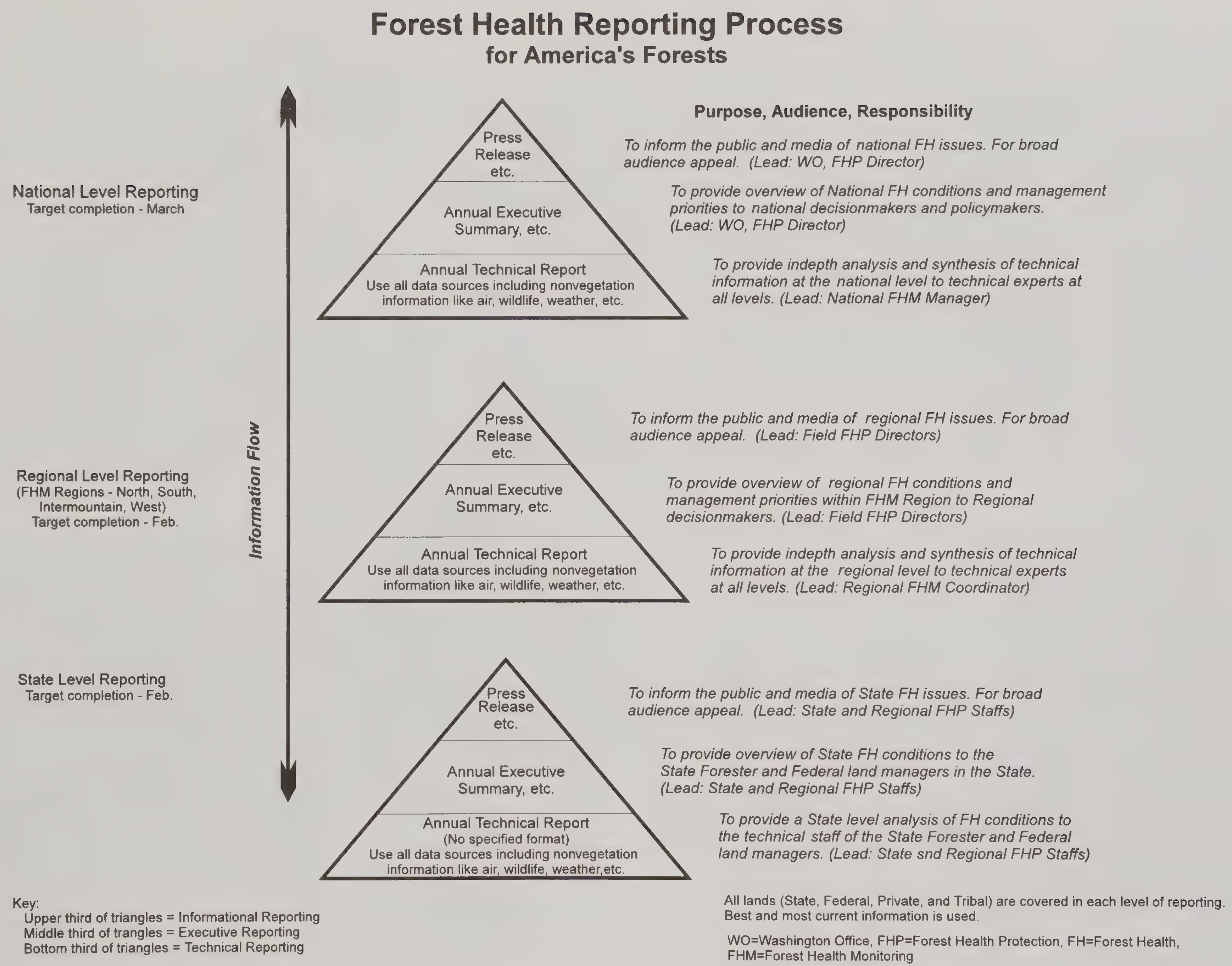

Figure 5—The process used to coordinate and share information among the State, regional, and national levels of monitoring. The triangles depict the amount of information generated for each level.

these land-use classes denotes an urban-and other-development condition (paved road, building, etc.). The urban land-use class was analyzed to evaluate the spatial pattern of the wildland/urban interface. This analysis was done for eastern plots measured in 1995 and for western plots measured from 1992 through 1995. From the analysis, spatial patterns of plots were evaluated. Plots were classified as all forest, no forest, forest/urban interface, and forest/nonurban interface. The nonurban condition class is composed of water bodies, meadows, pastures, etc.

The spatial pattern of the forest/urban interface shows relatively large areas of the mid-Atlantic States (Virginia and West Virginia), the southern States (Georgia and Alabama), central Colorado, parts of northern California, and the Great Lakes States to have a relatively large number of plots with both forest and urban land-use conditions (fig. 6). Relatively large areas of New England and northern and western California have plots that are completely forested. A spatial association may exist between plots with forest/urban condition and forest/other condition, suggesting that forest areas on the edge of meadows, lakes, farms, etc., are areas where urbanization may occur.

Forest Vitality

Forest vitality refers to a broad suite of factors that affect the structure or function of forest ecosystems. These factors can be generally classed as natural or exotic biotic agents, abiotic stressors, and anthropogenic emissions and manipulations of the forests. One of the principal criteria presented in the Santiago Declaration, forest vitality was a primary focus area of the FHM program before the Declaration. As such, many of the indicators used in FHM since 1990 are parallel to those suggested in the Santiago Declaration (table 1). Other indicators, such as crown dieback, while not explicitly identified as indicators of forest vitality in the Santiago Declaration, are indicators of stressors that can lead to the decline and mortality of trees and forest stands (Houston 1981).

Dieback

Crown condition is an important indicator of individual tree and forest stand health. It has been related to tree diameter growth and, consequently, basal area and volume increment. Generally, trees with large, full crowns have the potential to maximize gross photosynthesis because they are capable of capturing a large part of the solar radiation available annually. However, because net growth depends on site and stand conditions, as well as maintenance respiration costs, one simple crown condition indicator reflecting only crown size is inadequate. To assess crown condition, numerous indicators have been developed and used to detect various states of crown decline resulting from natural and anthropogenic stresses.

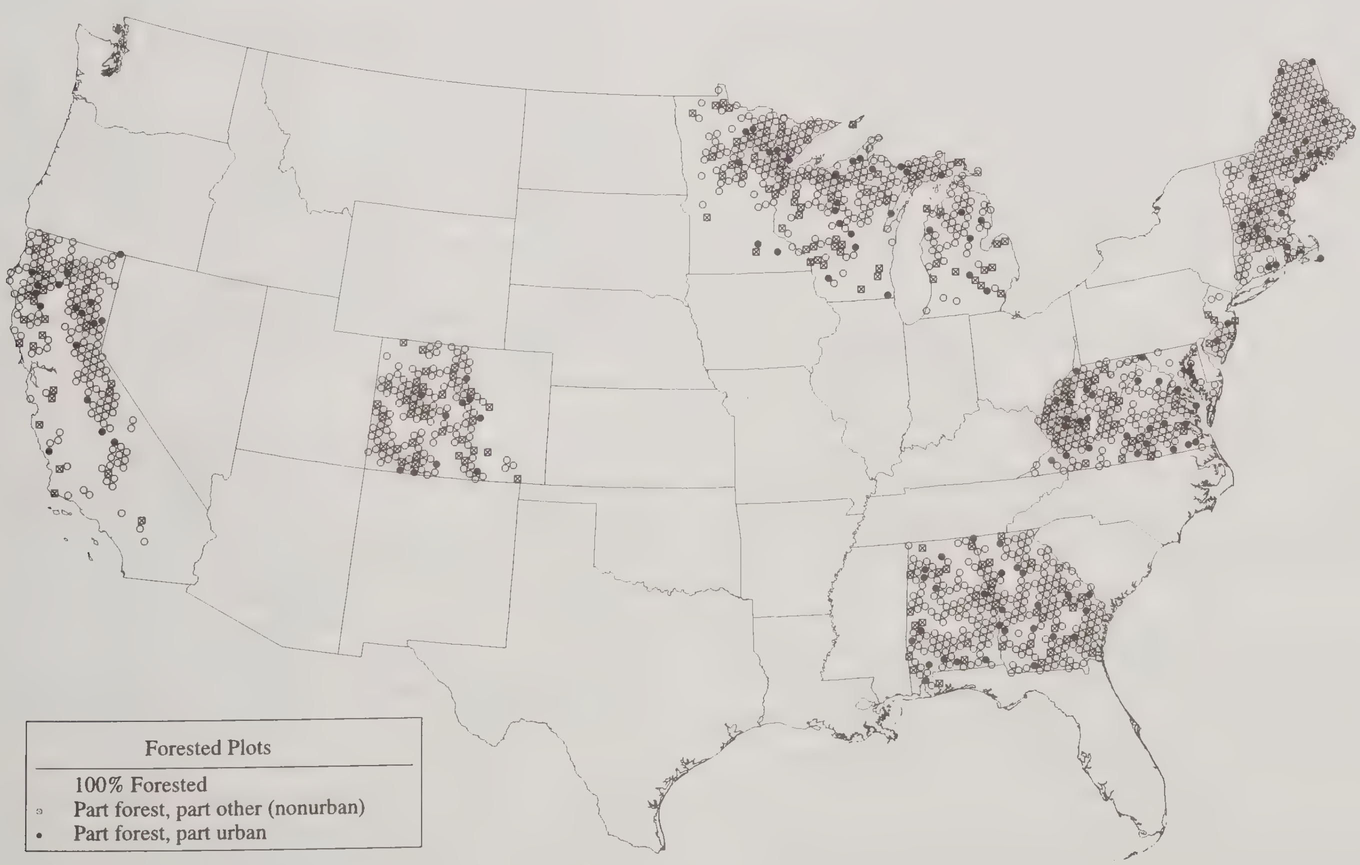

Figure 6—Spatial pattern of forest fragmentation based on condition classes on the Forest Health Monitoring plots.

In recent decades, dieback and decline have contributed to the death or damage of millions of trees in the Northeastern United States (Houston 1981). Although only a few species are commonly affected, often they are the most important ones relative to the needs of humans. For example, the gypsy moth has caused significant decline and mortality of oak species throughout much of the Eastern United States.

In areas where significant declines have occurred, other components of the forest ecosystem have also been significantly altered (Houston 1981). Leaf litter is reduced and may be sparse, greatly increasing the risk of soil erosion and reducing habitat for many natural gypsy moth predators. Understory growth is altered increasing both the number of native understory plant species and the potential for invasion by opportunistic exotic species.

Tree crown dieback is an important early warning indicator of potentially serious decline and tree death because it is a recognizable, visible symptom of the early stages of decline (Houston 1981). Dieback and decline are parts of a disease complex that have similar causal agents. An adverse environmental stress factor (primary stressor), such as drought, foliage and bark insects, soil compression, deicing salts, late spring frosts, and air pollution, first affects the tree. This initial stress weakens the tree by lowering starch reserves and can result in lethal attacks by other organisms that would not normally cause tree mortality (secondary stressors). The general pattern observed when primary and secondary stressors do not allow recovery is dieback-decline-death. If the primary stress abates before secondary stressors act, the tree can fully recover over time. All species should be monitored for early evidence of decline as indicated by dieback of the sun-exposed terminals of the crown. Currently, species of concern in the Eastern United States include white ash, beech species, sugar maple, local populations of Fraser fir and red spruce, and oak species; in the Western United States, interior ponderosa pine.

Site conditions strongly influence some of the dieback-decline cycles (Houston 1981). For example, gypsy moths in New England prefer oaks on dry sites such as rocky ridges or deep sands. These trees tend to be slow growing, small, and scrubby with rough bark that provides good resting sites for the moths. Often these oak stands have a history of disturbance, sometimes frequently, by fire, wind, snow, or ice storms.

Crown dieback is recorded in the FHM program as the percent mortality (in 5 percent classes) of the terminal portion of branches that are <1 inch [2.54 centimeters (cm)] in diameter and in the upper, sun-exposed portion of the crown ($0 \leq$ crown dieback ≤ 100) (Burkman and others 1995). In this report, the spatial pattern of mean dieback (plot-level average for all plots where number of trees ≥ 5) was evaluated. The spatial patterns were stratified by all species, hardwood species, softwood species, oak species, and sugar maple throughout the 18 States currently participating in the Plot Component of Detection Monitoring. Species delineations were based on Society of American Foresters nomenclature (Eyre 1980). Average dieback was grouped into three classes for each stratum: 0 to 7.5 percent, 7.6 to 15 percent, and >15 percent. In general, this represents plots with none to relatively low average dieback, relatively moderate average dieback, and relatively high average dieback (Forest Health Monitoring 1994a). Quantitatively linked to reductions in growth and mortality rates for some species and recognized as an initial symptom in several decline patterns (Houston 1981), degree of dieback can be used to indicate where the potential for serious declines in tree health is elevated.

Table 2 shows the average crown dieback for all plots within each implemented or pilot-tested State that was part of the Plot Component of Detection Monitoring during the years 1990 through 1995. This allows comparison of the relative amount of dieback in each State. The spatial pattern of average tree crown dieback for all species across all plots (fig. 7) indicates average dieback levels are highest in the western parts of the northern New England States (range 4.4 to 6.9 percent), the northern parts of the Great Lakes States (range 4.5 to 5.5 percent), and southern West Virginia and Virginia (range 3.8 to 5.5 percent) (table 2). This corresponds to parts of the Laurentian Mixed Forest Province and the northern extreme of the Southeastern Mixed Forest Province (Bailey 1995). In contrast, Georgia in 1995 and California in 1993 and 1994 experienced relatively low average dieback (table 2).

When the spatial pattern of hardwood species dieback was evaluated (fig. 8), hardwoods (range 3.7 to 8.5 percent) in the States previously identified for all species, as well as parts of West Virginia and northern California, are experiencing relatively moderate to high levels of dieback (table 2). The spatial pattern of dieback for softwood species (fig. 9) indicated relatively few plots with relatively high averages of dieback in any area except for the western portion of Virginia.

The spatial pattern of average crown dieback of oak species (fig. 10) indicated relatively high plot-level averages for parts of New England (range 4.3 to 7.1 percent), western Virginia, parts of the Great Lakes States (range 5.1 to 6.1 percent), and northern California (fig. 10). The spatial pattern of average crown dieback of sugar maple indicated that relatively moderate to high dieback averages are scattered in the northern New England States and parts of the Great Lakes States (fig. 11).

Average crown dieback was much higher on hardwood species than on softwood species, particularly in areas of New England, the Great Lakes States, some mid-Atlantic States, and the Western States. For example, average

Table 2—Average crown dieback for all implemented or pilot-tested States for the years from 1990 to 1995

Year	State	Average dieback	# Plots all species	Average hard-wood dieback	# Plots hard-wood	Average oak dieback	# Plots oak	Average soft-wood dieback	# Plots soft-wood
1990	CT	3.11	10	3.36	10	6.10	4	2.50	3
1990	MA	5.89	18	6.59	18	8.45	10	2.42	10
1990	ME	6.98	110	10.03	88	6.53	3	3.86	89
1990	NH	9.20	32	10.55	30	11.90	6	6.48	20
1990	RI	3.85	2	3.85	2	5.80	1	--[a]	--[a]
1990	VT	5.50	24	7.63	22	--[b]	--[b]	2.83	16
1991	AL	3.87	117	4.81	99	5.06	54	2.41	63
1991	CT	4.79	10	5.28	10	6.08	5	0.30	2
1991	DE	6.20	1	6.40	1	8.10	1	--[a]	--[a]
1991	GA	3.09	122	4.62	82	4.90	43	1.20	75
1991	MA	6.50	17	6.95	16	8.03	8	6.29	7
1991	MD	3.65	13	3.87	13	5.48	5	2.88	4
1991	ME	6.22	112	8.95	89	4.63	3	3.18	89
1991	NH	3.54	29	4.19	27	5.80	6	2.58	17
1991	NJ	7.26	16	7.22	12	8.22	6	6.79	8
1991	RI	3.40	1	3.40	1	2.90	1	--[a]	--[a]
1991	VA	5.33	96	6.06	90	7.00	56	2.99	38
1991	VT	4.05	21	5.85	19	--[b]	--[b]	1.35	12
1992	AL	4.87	114	5.14	97	5.80	51	4.13	59
1992	CA	5.11	48	8.43	29	10.07	20	2.61	32
1992	CO	3.95	34	5.70	16	18.90	1	3.36	27
1992	CT	5.15	11	5.45	11	5.60	5	2.00	3
1992	DE	3.40	1	3.40	1	5.60	1	--[a]	--[a]
1992	GA	3.39	132	3.99	86	4.58	42	2.34	83
1992	MA	6.44	21	7.05	20	7.14	11	4.56	10
1992	MD	5.06	14	5.35	14	6.13	6	1.00	4
1992	ME	5.24	115	7.21	92	4.45	2	2.78	91
1992	NC	1.51	15	1.88	12	4.65	6	1.28	11
1992	NH	4.33	33	5.42	31	7.12	6	1.52	20
1992	NJ	5.34	16	6.06	12	9.58	6	3.94	8
1992	RI	13.10	1	13.10	1	6.70	1	--[a]	--[a]
1992	SC	4.46	7	7.03	4	7.55	2	3.17	6
1992	TN	1.30	6	1.68	5	1.80	5	2.03	3
1992	VA	5.49	111	6.13	102	6.79	63	2.94	48
1992	VT	5.63	24	7.95	22	--[b]	--[b]	3.00	16
1993	AL	4.46	106	4.92	89	6.14	48	3.64	53
1993	CA	1.31	37	2.99	20	2.93	15	0.51	27
1993	CO	3.20	30	4.99	8	6.70	1	2.86	26
1993	CT	12.71	11	8.86	11	8.88	5	26.30	3
1993	DE	4.20	1	4.50	1	6.90	1	--[a]	--[a]
1993	GA	3.29	130	4.01	84	4.46	42	2.71	80
1993	MA	4.99	21	5.82	20	5.22	11	3.54	10
1993	MD	2.37	14	2.61	14	4.35	6	1.13	4
1993	ME	6.85	115	8.54	91	6.40	2	4.36	91
1993	NC	4.45	20	3.71	15	4.21	9	3.28	13
1993	NH	7.42	33	8.17	31	9.17	6	6.48	20
1993	NJ	5.14	16	5.20	12	5.60	6	4.76	8
1993	RI	12.00	1	12.00	1	7.50	1	--[a]	--[a]

Table 2—Average crown dieback for all implemented or pilot-tested States for the years 1990 to 1995 (continued)

Year	State	Average dieback	# Plots all species	Average hard-wood dieback	# Plots hard-wood	Average oak dieback	# Plots oak	Average soft-wood dieback	# Plots soft-wood
1993	SC	4.22	5	4.66	5	6.47	3	3.70	4
1993	TN	1.00	7	1.48	6	2.32	5	0.18	4
1993	VA	4.66	101	5.00	94	5.43	58	4.37	39
1993	VT	6.46	22	8.12	21	--[b]	--[b]	5.91	14
1994	AL	4.12	97	4.09	82	5.00	40	4.27	46
1994	CA	1.51	44	2.40	21	3.00	15	0.35	29
1994	CO	4.23	33	5.67	9	16.45	2	3.63	30
1994	CT	4.42	11	3.02	11	3.42	5	9.53	3
1994	DE	4.80	1	5.00	1	8.30	1	--[a]	--[a]
1994	GA	2.14	106	3.52	70	3.98	33	0.70	63
1994	MA	6.27	22	6.77	21	6.69	11	4.91	10
1994	MD	2.10	14	2.37	14	4.53	6	0.63	4
1994	ME	7.12	115	9.17	91	7.20	2	4.09	91
1994	MI	4.19	117	5.09	103	5.99	19	3.09	51
1994	MN	5.20	100	5.79	81	3.74	21	5.04	42
1994	NH	6.68	33	7.44	31	6.96	5	5.17	19
1994	NJ	4.35	16	4.55	12	5.53	6	4.04	8
1994	OR	1.50	12	1.71	7	0.00	1	1.10	12
1994	RI	9.50	1	9.50	1	5.40	1	--[a]	--[a]
1994	VA	2.60	88	2.73	81	3.47	52	1.52	32
1994	VT	6.02	22	7.80	21	--[b]	--[b]	2.58	12
1994	WA	1.33	10	1.85	4	--[b]	--[b]	1.08	10
1994	WI	3.99	79	4.48	68	5.77	18	1.89	24
1995	AL	3.15	117	3.53	95	3.98	48	2.55	66
1995	CA	3.42	36	5.40	21	6.56	17	1.91	28
1995	CO	3.52	37	3.51	10	6.55	2	3.31	31
1995	CT	4.39	11	3.68	11	6.58	4	7.00	3
1995	DE	1.60	1	1.80	1	2.50	1	--[a]	--[a]
1995	GA	1.81	132	2.75	88	3.92	43	1.22	84
1995	MA	6.04	22	6.36	21	6.91	11	5.23	11
1995	MD	2.43	14	2.72	14	5.44	5	0.33	4
1995	ME	6.85	113	8.54	91	7.13	3	4.87	91
1995	MI	4.48	114	5.54	102	5.09	18	3.39	47
1995	MN	5.52	100	7.44	81	6.13	20	2.33	41
1995	NH	5.22	33	6.02	31	4.32	6	3.21	19
1995	NJ	3.65	16	3.93	12	4.90	6	3.19	8
1995	PA	2.80	22	2.79	22	4.12	9	5.00	1
1995	RI	3.10	2	3.10	2	2.50	1	--[a]	--[a]
1995	VA	5.53	93	5.12	86	6.57	56	5.92	40
1995	VT	5.98	22	7.66	21	--[b]	--[b]	2.83	12
1995	WI	4.87	74	5.22	63	6.22	19	3.84	22
1995	WV	3.84	69	4.00	68	3.13	33	0.75	2

[a] No plots had ≥ 5 softwood trees.
[b] No plots had ≥ 5 hardwood trees.

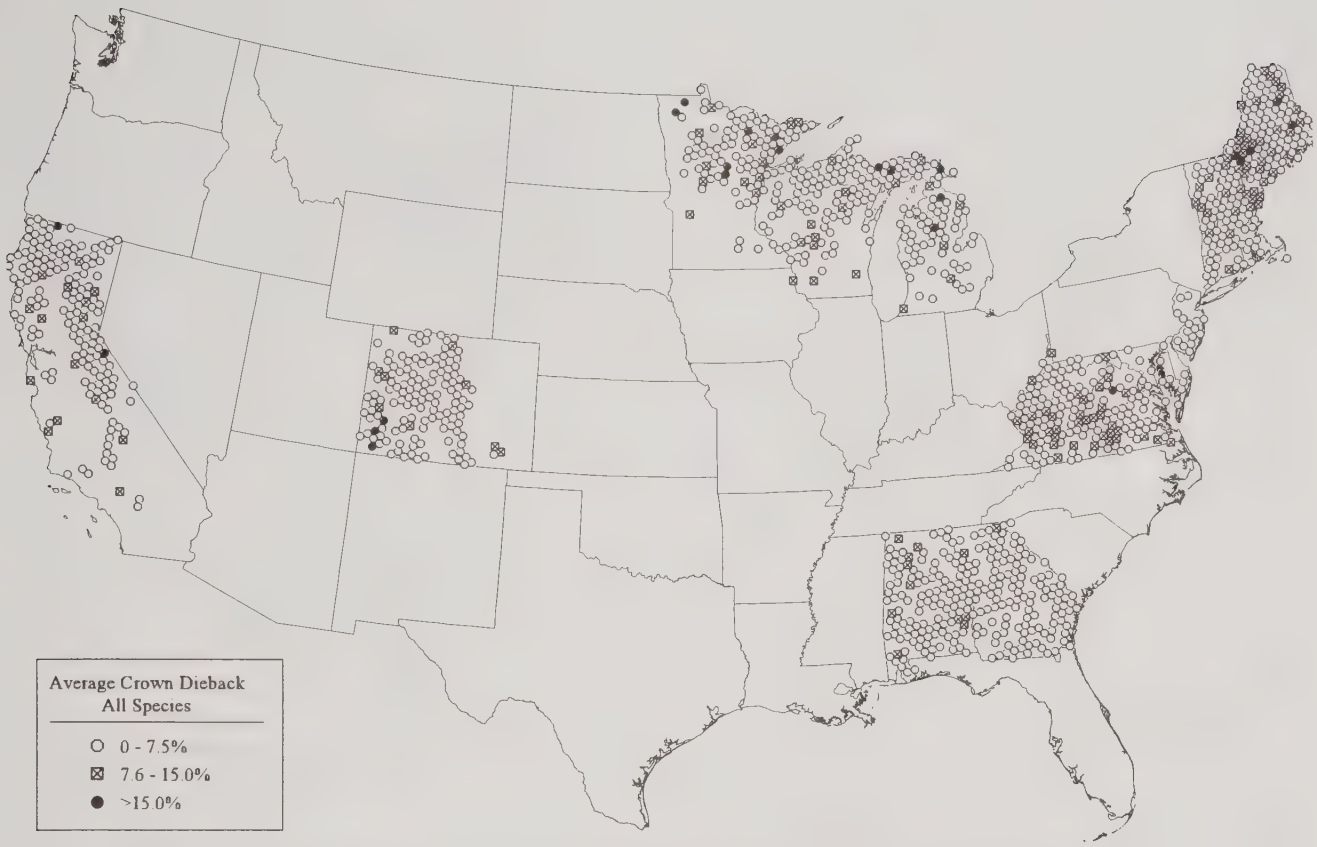

Figure 7—Spatial pattern of average tree crown dieback for all species, 1993 through 1995 in the West and 1995 in the East.

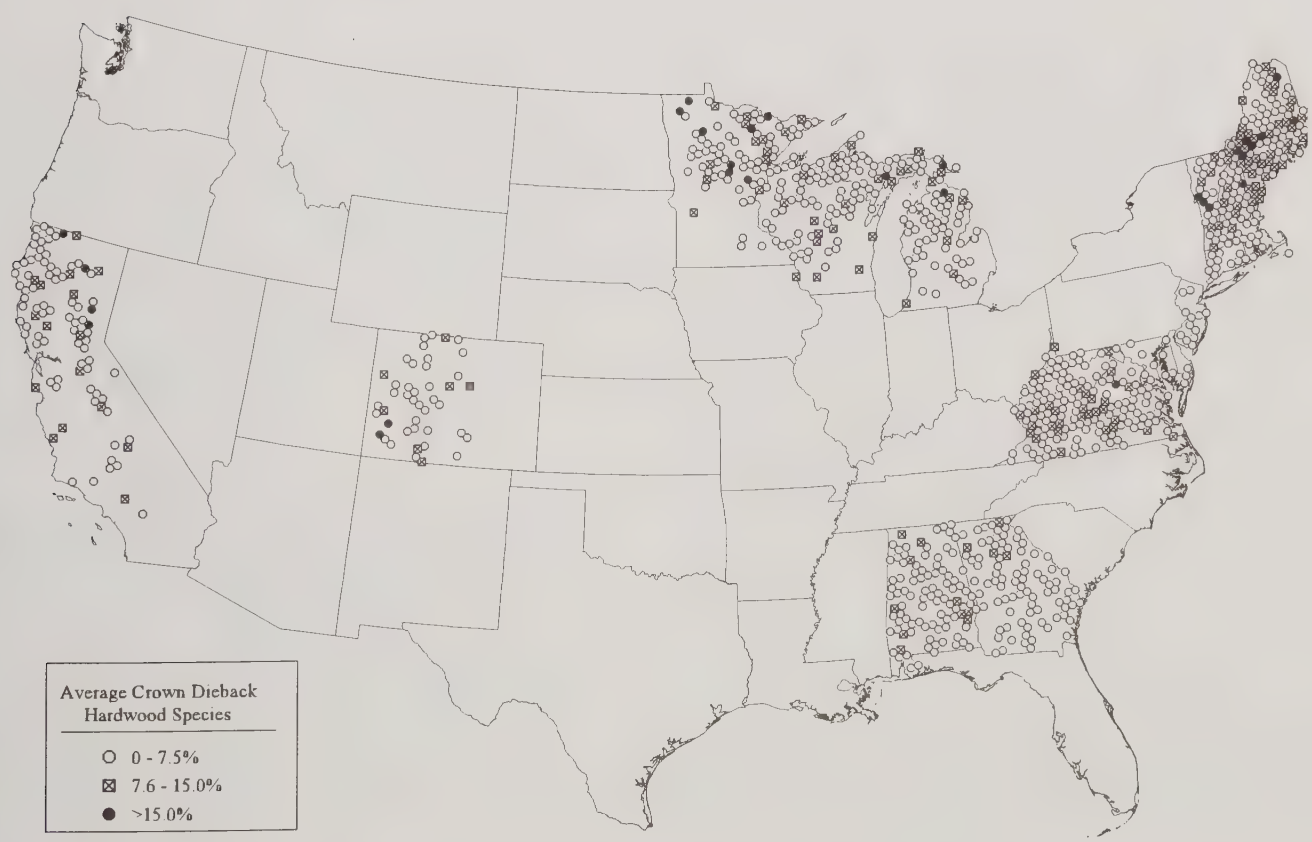

Figure 8—Spatial pattern of average tree crown dieback for hardwood species, 1993 through 1995 in the West and 1995 in the East.

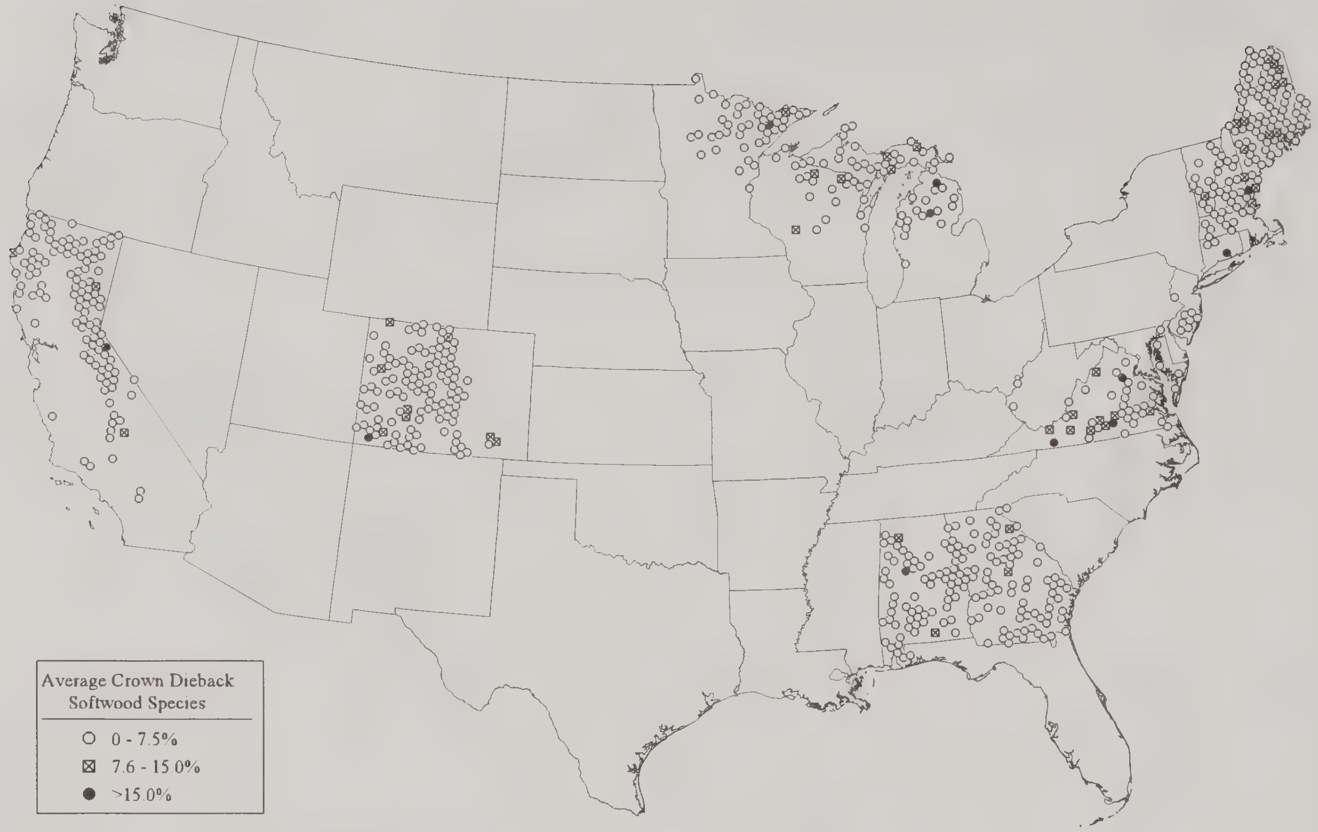

Figure 9—Spatial pattern of average tree crown dieback for softwood species, 1993 through 1995 in the West and 1995 in the East.

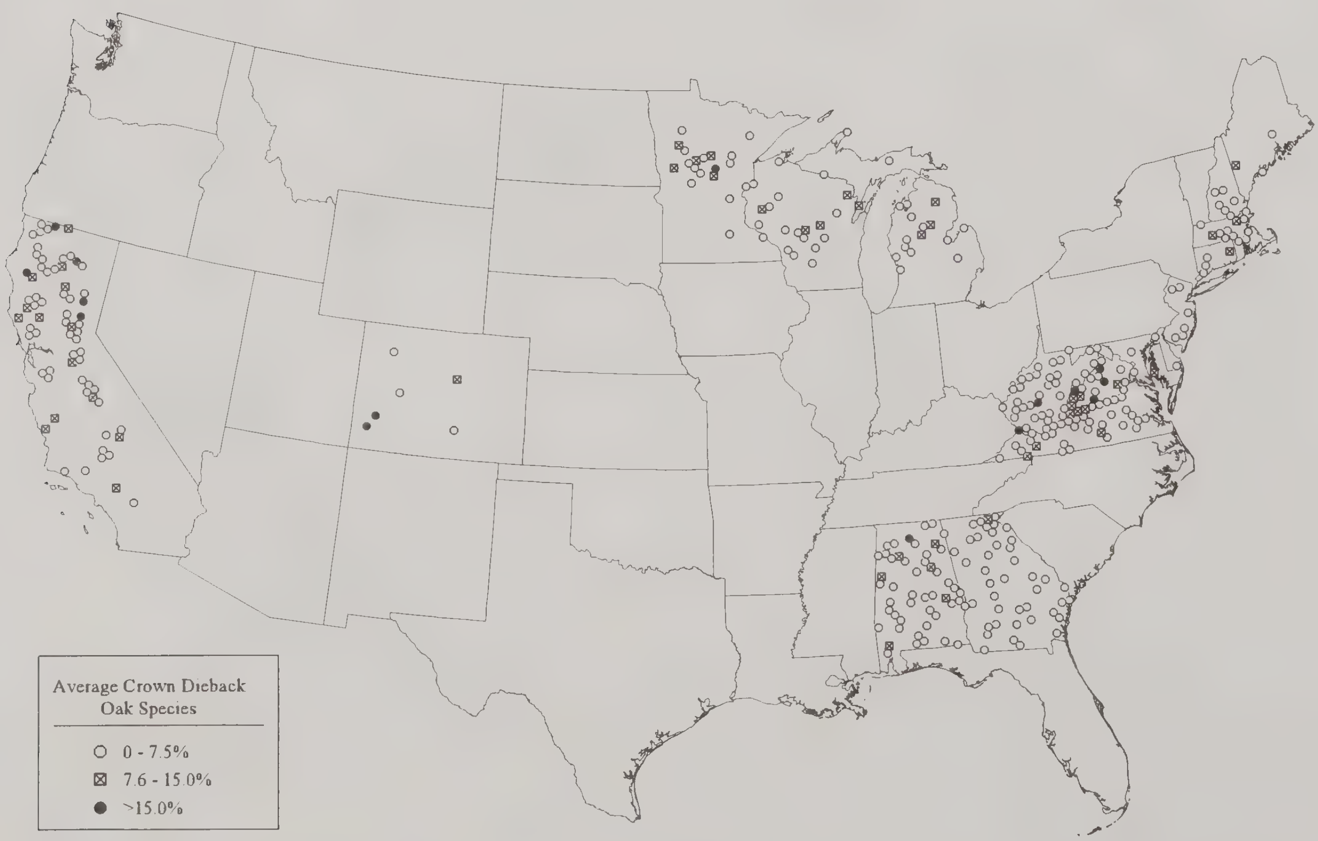

Figure 10—Spatial pattern of average tree crown dieback for oak species, 1993 through 1995 in the West and 1995 in the East.

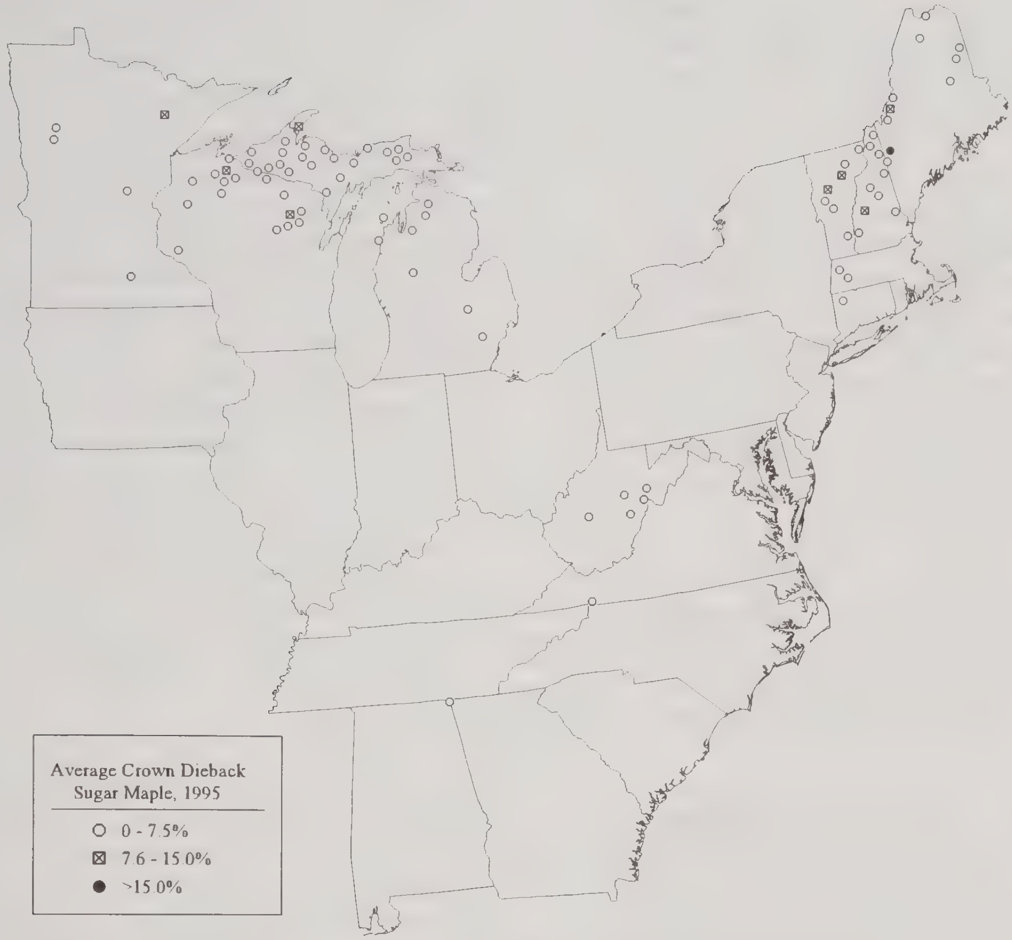

Figure 11—Spatial pattern of average tree crown dieback for sugar maple in 1995 in the East.

dieback of hardwoods was 2 to 3 times higher than on softwoods in Maine (8.5 vs. 4.9 percent), Vermont (7.7 vs. 2.8 percent), Minnesota (7.4 vs. 2.3 percent), West Virginia (4.0 vs. 0.8 percent), and California (5.4 vs. 1.9 percent). Crown dieback of oak species suggests possible spatial clustering in western Virginia, northern California, and parts of some Great Lakes States. Few plots had relatively high levels of crown dieback of sugar maples, and little spatial clustering of the few plots that do have higher dieback levels occurring.

Damage

Damage caused by pathogens, insects, storms, and human activities can significantly affect the growth, reproduction, and mortality of trees.[2] In the FHM program, tree damage is recorded only if it is considered serious enough to increase the probability that a tree will be infected by lethal pathogens (such as open wounds or broken branches), that a tree will die prematurely (presence of pathogenic conks, cankers, or broken roots), or that the growth and/or reproduction of the tree will be seriously depressed (such as high defoliation or broken branches). To be recorded, damages must meet or exceed set thresholds; i.e., >20 percent bole circumference with an open wound; >30 percent of the foliage damaged more than 50 percent (Mielke and others 1995). Only serious damage is recorded, and damage estimates are repeatable and comparable from State to State. This approach to quantifying tree damage produces an estimate of damage severity at the plot level.

Tree damage is analyzed as incidence of damage and severity of damage. Incidence of damage is an analysis of the number of trees affected by significant damage, thus indicating the frequency of encountering damaged individuals. The severity of damage is a quantification of the amount of damage at the plot level. Analyzing both incidence and severity of damage gives some indication about the proportion of trees injured and the gravity of the damage to the affected trees.

Damage incidence—Incidence of tree damage is simply the number of trees on a plot with one or more damages divided by the total number of trees on the plot. Tree-damage incidence can help differentiate whether damage severity at the plot level represents a few trees badly damaged or many trees with less severe damage. Because

[2] Mielke, M.E., Krupa, S. Damage and catastrophic mortality. Manuscript in preparation.

only serious damages are reported, incidence of damage is a good indicator of the percentage of trees on a plot with an increased probability of reduced growth or premature mortality.

The spatial pattern of damage incidence was visually evaluated for the Eastern States in 1995 and evaluated using plot-level values for the Western States in 1993 through 1995. Damage data before 1993 were not used because field methods changed significantly in 1993. The spatial pattern of tree damage incidence for all species indicated that more than 20 percent of the trees per plot had significant damage in many plots in the Northeast and Great Lakes States (fig. 12). Some plots in the mid-Atlantic States, Colorado, and California had similar average numbers of damaged trees.

Tables 3, 4, and 5 show the average percent of trees damaged in the East and West for the years 1993 through 1995. Because the number of plots in this class decrease from north to south, the high number of trees injured may reflect the more severe winters that occur in northern forests each year.

Areas with a relatively low percentage of trees damaged include southern Virginia, northern Alabama and Georgia, and northern California (fig. 12). When all species are stratified into hardwood and softwood species, hardwood species in California have more plots with higher levels of percent trees damaged (fig. 13) than softwood trees (fig. 14). In Colorado, hardwood and softwood trees had similar amounts and distribution of tree damage.

Damage severity—Tree damage severity is composed of three variables: location on the tree, type of symptom, and severity of the symptom. Location of the injury affects the severity; for example, injury near the base of the tree is more serious than injury near the apex of the tree because parts of the crown can be lost without killing the tree. Similarly, some damage symptoms are more serious than others; for example, open wounds can heal if they do not become infected and therefore are not as serious as cankers, which are caused by fungi that kill the bark and cambium. The severity of the symptom is simply an estimate of the area affected; for example, a canker affecting 80 percent of the tree-bole circumference is more serious than a similar canker affecting 30 percent of the tree-bole circumference. These three variables are combined in a multiplicative index (see footnote 2) to score each tree for damage. This index was developed following several workshops of Federal, State, and university experts in forest pathology and entomology.

Tree scores are aggregated to plot-level scores. Up to three damages per tree can be scored. The damage index has a range of 0 to 21.7; that is, a tree with three serious damages of maximum severity occurring near the base of the tree would have a damage index score approaching 21.7. In general, a tree (or plot-level aggregates of tree species, types, etc.) with a high damage index indicates multiple

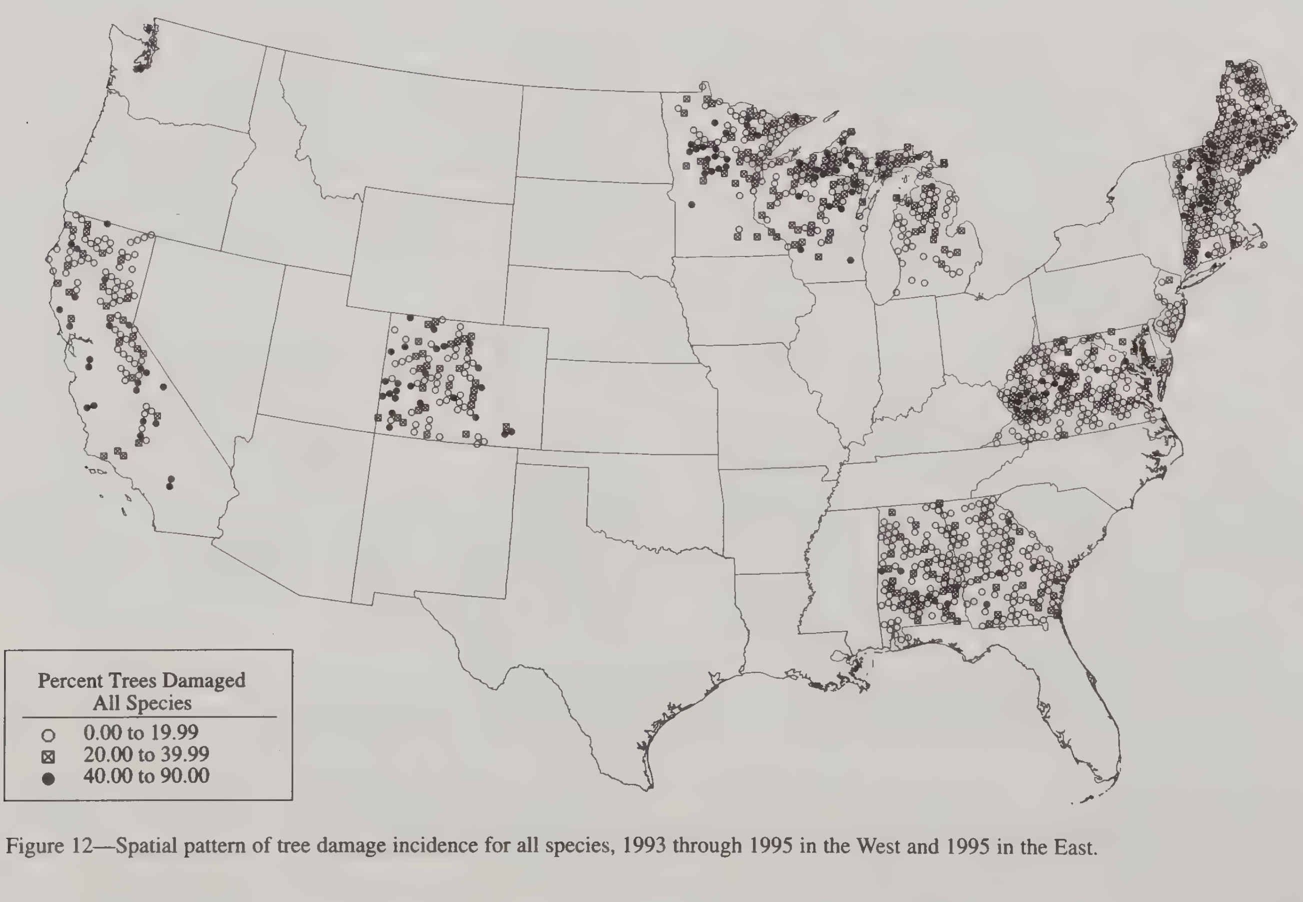

Figure 12—Spatial pattern of tree damage incidence for all species, 1993 through 1995 in the West and 1995 in the East.

Table 3—Average tree damage incidence in 1993 in all implemented States

State	Average[a] pct. damage all species	# Plots all species	Average pct. damage hardwoods	# Plots hardwoods	Average pct. damage softwoods	# Plots softwoods
New England States						
CT	45.63	10	43.57	10	49.96	3
MA	16.86	21	19.04	20	16.07	10
ME	20.28	115	26.50	90	12.45	85
NH	20.65	33	26.06	31	5.54	19
RI	37.50	1	37.50	1	--[b]	--[b]
VT	34.38	22	38.21	21	24.51	11
Mid-Atlantic States						
DE	32.00	1	31.82	1	--[b]	--[b]
MD	31.54	14	34.31	14	2.78	4
NJ	15.26	16	14.95	12	15.35	8
Southeast States						
AL	16.65	107	18.64	86	10.98	47
GA	12.49	105	12.46	67	13.80	61
VA	16.03	89	17.71	80	6.58	32
Western States						
CA	19.91	37	27.53	19	15.56	27
CO	23.16	28	42.49	8	20.00	23

[a]Percent of trees damaged on plots, averaged for plot.
[b]No plot had ≥ 5 softwood trees.

Table 4—Average tree damage incidence in 1994 in all implemented States

State	Average[a] pct. damage all species	# Plots all species	Average pct. damage hardwoods	# Plots hardwoods	Average pct. damage softwoods	# Plots softwoods
New England States						
CT	34.09	10	32.86	10	44.71	3
MA	16.84	22	19.40	21	16.05	10
ME	21.29	115	27.38	88	13.75	86
NH	17.55	33	23.00	31	2.28	18
RI	34.78	1	34.78	1	--[B]	--[B]
VT	31.51	22	34.65	21	18.34	11
Mid-Atlantic States						
DE	52.17	1	55.00	1	--[B]	--[B]
MD	29.77	14	31.83	14	2.50	4
NJ	13.82	16	16.78	12	9.87	8
Great Lakes States						
MI	23.68	115	25.65	102	16.99	48
MN	27.10	99	30.41	76	18.06	39
WI	32.45	73	35.05	65	19.65	21

Table 4—Average tree damage incidence in 1994 in all implemented States (continued)

State	Average[a] pct. damage all species	# Plots all species	Average pct. damage hardwoods	# Plots hardwoods	Average pct. damage softwoods	# Plots softwoods
Southeast States						
AL	16.06	98	17.80	79	12.23	43
GA	10.64	102	10.48	65	10.55	59
VA	17.16	86	19.18	78	6.60	29
Western States						
CA	24.64	43	35.06	19	16.00	29
CO	28.16	33	44.42	8	22.56	30
OR	21.00	12	36.73	5	15.05	12
WA	16.68	10	16.30	3	15.49	10

[a] Percent of trees damaged on plots, averaged for plot.
[b] No plot had ≥ 5 softwood trees.

Table 5—Average tree damage incidence in 1995 in all implemented States

State	Average[a] pct. damage all species	# Plots all species	Average pct. damage hardwoods	# Plots hardwoods	Average pct. damage softwoods	# Plots softwoods
New England States						
CT	29.46	11	28.69	11	46.93	3
MA	12.87	22	16.25	21	10.35	10
ME	21.87	112	29.03	88	11.22	84
NH	31.17	33	38.39	31	11.36	18
RI	30.00	2	30.56	2	--[b]	--[b]
VT	30.41	22	35.95	21	14.25	12
Mid-Atlantic States						
DE	40.91	1	40.00	1	--[b]	--[b]
MD	28.19	14	31.24	14	2.63	4
NJ	11.44	16	12.59	12	8.66	8
PA	35.24	22	35.78	22	20.00	1
WV	24.22	69	24.43	68	0.00	2
Great Lakes States						
MI	22.38	113	25.21	101	17.75	45
MN	24.14	99	29.07	77	8.39	39
WI	25.21	68	29.45	59	12.81	21
Southeast States						
AL	12.93	113	13.92	88	9.87	60
GA	9.14	128	13.04	80	6.11	79
VA	10.11	91	12.03	83	2.52	34
Western States						
CA	25.60	36	43.11	19	16.60	28
CO	27.92	37	32.44	10	25.12	31

[a] Percent of trees damaged on plots, averaged for plot.
[b] No plot had ≥ 5 softwood trees.

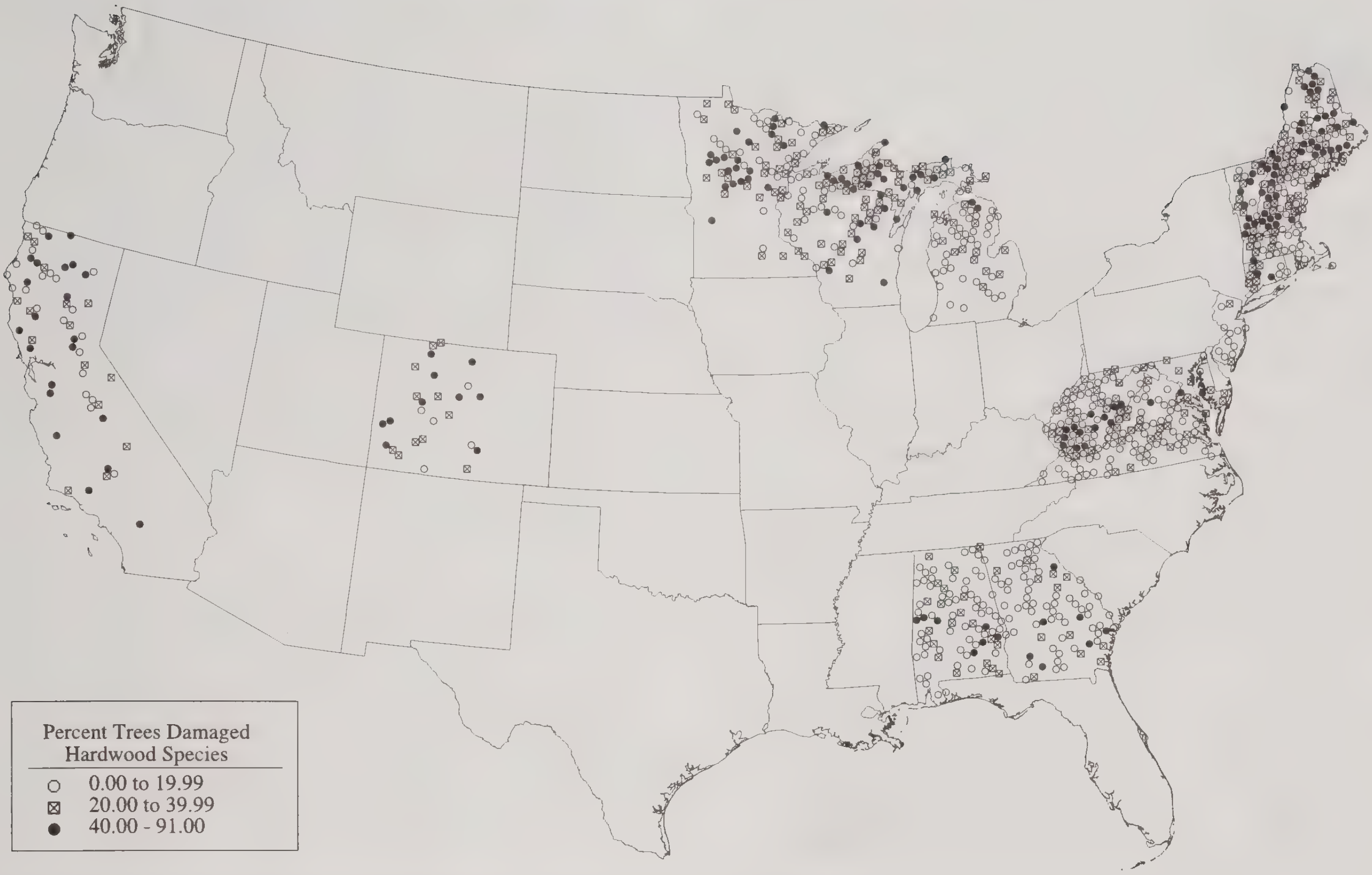

Figure 13—Spatial pattern of tree damage incidence for hardwood species, 1993 through 1995 in the West and 1995 in the East.

Figure 14—Spatial pattern of tree damage incidence for softwood species, 1993 through 1995 in the West and 1995 in the East.

damages, severe types of damage, and extensive damages with the damages occurring near the base of the tree. The damage index (DI) for the plot is computed as:

$$DI_{plot} = (d_1 \, l_1 \, s_1 + d_2 \, l_2 \, s_2 + d_3 \, l_3 \, s_3)_{tree} / n \qquad (1)$$

where
d = damage type (1 to 3 per tree),
l = location of damage (1 to 3 per tree),
s = severity of damage (1 to 3 per tree), and
n = number of trees per plot.

For evaluation of spatial patterns, the range of plot-level damage index scores was divided into three classes: 0 to 1.8, 1.9 to 3.6, and 3.7 to 14.0. Because most trees typically have only one serious damage (see footnote 2), the 0 to 1.8 range can be broadly interpreted to represent plots where, at a maximum, 25 percent of the trees have one serious damage in a critical location.

The spatial pattern of tree damage severity for all species indicates that the highest numbers of plots with relatively severe damage occurred in the Great Lakes States (fig. 15). Hardwood species had the highest relative damage severity in the Great Lakes States, in the northern parts of New England, and to a lesser extent, in the two Western States (fig. 16). Softwood species in general were not as damaged as hardwood species, although some parts of the Great Lakes States, northern New England, and southern Alabama had groups of plots with relatively high damage levels (fig. 17).

The combination of biotic and abiotic damage to trees was highest for hardwood species and most common in the Great Lakes States and parts of New England. While the number of trees damaged was relatively high in several areas of the country, the damage severity was relatively high only in parts of the Great Lakes States and New England, suggesting that, in many cases, the number and severity of the damages overall were relatively low. That is, even though more than 20 or 40 percent of the trees on a plot might be damaged, the damage to most trees was not very severe.

Insects and Disease

Major insects and diseases—Native insects and diseases are an integral part of forest ecosystems that kill weakened and senescent trees to make way for new, vigorous forests. They also help recycle forests by decomposing trees to replenish the soil and supply vital nutrients necessary for forest growth. The process of forest regeneration, growth, and renewal has repeated for millennia and is essential to stable, healthy forest ecosystems.

However, human need for lumber and other wood products often conflicts with the natural loss of these products through insects and diseases. Insect and disease outbreaks

Figure 15—Spatial pattern of tree damage severity for all species, 1993 through 1995 in the West and 1995 in the East.

Figure 16—Spatial pattern of tree damage severity for hardwood species, 1993 through 1995 in the West and 1995 in the East.

Figure 17—Spatial pattern of tree damage severity for softwood species, 1993 through 1995 in the West and 1995 in the East.

also affect other resources valued by society such as aesthetics, recreation, water, and wildlife. Forest resource managers face the continuing challenge of meeting society's needs within the broader and inevitable context of ecosystem cycles.

As global interactions increase, the threat of exotic pests being introduced into the United States increases. The USDA Forest Service and other USDA agencies are working to reduce the spread of exotic insects, diseases, and plants that threaten forest ecosystems. Introduced insects and diseases are not integral parts of our forest ecosystems. By not evolving with U.S. ecosystems, these organisms cause new and sometimes devastating effects that can change ecosystems forever. For example, chestnut blight, white pine blister rust, gypsy moth, Dutch elm disease, and beech bark disease have disrupted several forest ecosystems by greatly reducing or eliminating some forest tree species from their native habitats. Today, introduced agents pose a continuing threat to U.S. forests.

In addition, human activities have caused some unexpected and unwanted consequences involving native organisms. One consequence is a change in the severity and extent of effects that organisms have on our forests. Fusiform rust and several root disease organisms exemplify how human use and management activities change the way native organisms affect forest ecosystems. These organisms of relatively little consequence in the past are now severe and widespread. Appendix A lists and describes some important insects and diseases affecting U.S. forests.

Forest Health Monitoring measures the effects of insects, infectious and noninfectious diseases, and other agents in two ways. First, forest damage measurements are made on FHM plots. Second, forest insect, disease, and other change agent effects are detected and reported using data from periodic aerial and ground surveys. The insect and disease information on acres of host type affected in 1995 was derived (table 6) from aerial and ground surveys (Forest Pest Management 1995).

In table 6, data for *Acres of Host Type Affected in 1995* (column four) are currently reported regionally and only consolidated nationally for a few of the major agents affecting forests. Data for columns three and five are incomplete because information on *Host Type at Risk* and *At-Risk Host Type Affected* are only available locally or for some USDA Forest Service regions. These data are primarily collected and reported to meet local management needs.

With two exceptions, the insects and disease-causing organisms in table 6 occupy their ecological niches within the host type and likely will not expand much farther. The exceptions—gypsy moth and dogwood anthracnose—will probably continue to infest new areas. The challenge for FHM involves defining the specific areas within generally susceptible host type that have become or will become susceptible to increasing activity by forest insects and disease-causing organisms.

The last two columns, *Percent Maximum Affected* and *Outlook*, show differences in how the listed agents affect forests. Insect activity is generally cyclical, primarily driven by forest condition and environmental factors (table 7). The *Percent Maximum Affected* (table 6) column shows current status as a percentage of previous high outbreak status—a reference point to put current activity in historical perspective. Though actual disease infection patterns are also cyclical, once an area is infested, it can remain infested for a long time unless suppression measures are taken or long-term forest changes take place.

Knowing how much, where, and why forests are or will be at risk to various agents is important to (1) understanding and predicting probable forest health consequences of insects, diseases, and environmental stress, and (2) developing short- and long-term strategies to prevent, suppress, or otherwise cope with expected insect and disease outbreaks and related forest health issues. Forest Health Monitoring participants are developing regional and national data collection standards and guidelines. Using these standards and guidelines to improve data comparability, data gaps will be filled and survey data will be used more effectively with other resource and environmental data in assessing current forest health status and predicting likely changes in forest condition.

Work is underway to establish and apply standards for survey activities. An eastwide plan, developed by the USDA Forest Service and State FHM participants, outlines specific standards and guidelines that will help the USDA Forest Service Northeastern Area, the USDA Forest Service Southern Region, and State FHM participants attain more comparable survey results. This plan addresses survey methods, quality assurance, minimum detection and mapping standards, and data to be reported with each mapped polygon. These data are State, county, forest type, damage causal agent, damage type, species damaged, and damage class. In addition, FHM plots located in outbreak areas and actually affected by pest outbreaks or other effects are noted. Western USDA Forest Service regions and States have begun the process of establishing standards and guidelines applicable to western conditions.

The initial minimum national detection standard states that all mortality, damage, or other change agent effects exceeding 5,000 contiguous acres will be found 90 percent of the time when more than one-half the area exhibits damage or other effects at or above specified mapping thresholds. More stringent standards can be applied to meet specific regional or State needs. General

Table 6—Insects and diseases affecting U.S. forests (in thousands of acres)

Agent	Acres of host type[a]	Acres of host type currently at most risk	Acres of host type affected in 1995	Percent of "at most risk" host type of host type	Amount of host type affected in 1995 as a percent of the maximum number of acres affected in the last 15 years (high year)	Outlook
Root disease pathogens	234,562	19,807	--[b]	8	--	Static.
Dwarf mistletoes	170,616	--	28,907	--	--	Gradual reduction in managed forests.
Fusiform rust	63,946	46,287[c]	13,483	72	98% (1994)	Gradual reduction in managed forests.
White pine blister rust	51,355[d]	--	--	--	--	Continued slow spread to uninfested areas.
Dogwood anthracnose	71,796[e]	--	17,949	--	100% (1995)	Continued spread to uninfested areas.
Gypsy moth	196,400[f]	103,400[f]	1,418	53	12% (1981)	Continued spread south and west. Localized outbreaks expected every year. Major outbreaks have occurred on an 8 to 10 year cycle.
Southern pine beetle	96,158	--	21,676	--	80% (1986)	Continued sporadic outbreaks of increasing severity.
Mountain pine beetle	49,245	--	576	--	12% (1981)	Outbreaks in late 1970's and early 1980's destroyed much of the susceptible host type. Insect activity currently at historical low. Estimated that it will take 60 to 80 years for host type to again be susceptible to widespread outbreaks.
Spruce budworm	19,687	--	569	--	2% (1978)	Outbreaks in late 1970's and early 1980's destroyed much of the susceptible host type. Estimated that it will take 30 to 40 years for host type to again be susceptible to widespread outbreaks.
Western spruce budworm	79,000	--	478	--	4% (1986)	Localized outbreaks expected. Future outlook uncertain.

[a] Based on FIA data.

[b] "--" indicates data are not available for national summarization. Site specific and regional data may be available.

[c] Starkey, D.A.; Anderson, R.L.; Cost, N.; Vissage, J.; May, D.M. 1996. Distribution and incidence of fusiform rust in the south. Unpublished Report.

[d] Acres where five-needle pines are a stand component.

[e] Acres where dogwood is a stand component in the eastern United States.

[f] For Eastern United States. Source: Liebhold, A.M.; Gottschalk, K.W.; Mason, D.W. 1996. Evaluation of forest susceptibility to the gypsy moth across the coterminous United States. World Wide Web document: http://gypsy.fsl.wvnet.edu/gmoth/suscept/suscept.html

Table 7—Acres of insect activity by years (in 1,000 acres)

Year	Gypsy moth[a]	Southern pine beetle[b]	Mountain pine beetle[c]	Spruce budworm[a]	Western spruce budworm[a]
1986	2,413	26,389	3,450	1,042	13,223
1987	1,329	13,796	2,442	680	7,953
1988	709	7,936	2,206	265	6,063
1989	2,996	5,333	1,614	145	3,140
1990	7,304	4,232	936	201	4,632
1991	4,152	10,744	617	108	7,171
1992	3,057	14,307	641	126	4,594
1993	1,784	10,414	782	116	447
1994	880	5,251	405	778	496
1995	1,418	21,676	576	569	478
Total	26,042	120,078	13,669	4,030	48,197
Average	2,604	12,008	1,367	403	4,820

[a] Acres of aerially-detected defoliation.
[b] Acres of host type with one or more multiple-tree spots per 1,000 acres.
[c] Acres of host type with one dead or dying tree per 10 acres.
Source: Forest Insect and Disease Conditions in the United States, reports 1986–95

damage/effect types are defoliation, discoloration, dieback, branch breakage, main stem broken/uprooted, and mortality. The current mapping threshold for discoloration, dieback, and branch breakage is more than 50 percent damage of more than 30 percent of the canopy area. The threshold for defoliation is more than 50 percent damage of more than 50 percent of the canopy area. The damage threshold for mortality and stem breakage/uprooting is more than 30 percent of the trees damaged.

Continued progress is needed both to develop and apply national and regional standards to FHM Survey Component activities. These standards will allow FHM and USDA Forest Service and State Forest Health Protection programs to better:

- Evaluate current forest health status,
- Analyze changes in forest health over time,
- Provide information for policy and management decisions,
- Link the Survey Component to FHM and other ground plot systems, and
- Report and display regional data.

Southern pine beetle risk assessment—The southern pine beetle (SPB) is a bark-boring beetle that feeds on and oviposits in the phloem tissue of southern yellow pines—especially loblolly and shortleaf pines. The pest ranges from New Jersey to eastern Texas and southward into Central America. The SPB is considered the most destructive pine pest throughout its range. Population levels fluctuate considerably through time and space and are believed to exhibit a cyclic nature resulting in regional epidemic outbreaks about every 5 to 10 years.

The vigor of individual trees that are attacked within a stand determines the success of SPB reproduction. Vigorous trees are capable of resisting SPB attack at endemic population levels by increasing oleoresin production (Payne 1981). At epidemic population levels, even the most vigorous trees can be overcome by the sheer number of beetles. It has also been reported that stand

disturbances, such as lightning or logging, provide the beetles with additional avenues for colonization (Ku and others 1980).

Trees of low vigor are selected by female *pioneer* beetles for colonization; therefore, soil, site, and climatic factors that reduce tree vigor also increase the risk of SPB infestation in pine stands. Bennett (1965) first discussed the predilection of dense, slow growing, sawtimber pine stands to SPB attack. Lorio and Hodges (1974) first proposed the use of soil, site, and climatic factors in assessing the risk to pine stands from the SPB. Discriminant analyses, probabilistic modeling, and qualitative stand-ranking approaches have been applied to assess the risk to pine stands from SPB infestation. Most published risk-prediction models correctly predicted which pine stands would be attacked in about three out of four cases (Lorio 1981).

Models for SPB risk assessment (in most cases, more correctly referred to as hazard-rating, i.e., the probability of mortality given an attack as opposed to risk, which is the probability of an attack) have been developed for many specific States and stand types. The models are generally a function of stand density, percent pine, and some measure of stand vigor, either radial growth explicitly or implicitly by including site index and age in the model. A model developed by Ku and others (1980) was applied to the FHM plots in Alabama, Georgia, Virginia, and Maryland. A single model was used for all States, as opposed to State and stand type specific models, for two reasons: first, available measurements were limited; and second, to avoid inconsistencies in model development, particularly in the definition of high, moderate, and low susceptibility. The model, developed using data from 984 infested and 509 uninfected pine stands in Arkansas by Ku and others (1980), was applied to FHM field measures of stand characteristics:

$$\begin{aligned} \textit{SPB Risk Score} &= -1.5(TBA) + 0.93(HBA) \\ &\quad + 3.3(AGE) + 64.3(RG) \end{aligned} \tag{2}$$

where
TBA = total basal area in square feet,
HBA = hardwood basal area in square feet,
AGE = stand age in years, and
RG = last 10 years' radial growth in inches.

Using this equation, scores >100 are considered low risk; those <0 are high risk; and those between 0 and 100 are moderate risk. Although the authors developed this model using data from undisturbed pine stands on upland flats in Arkansas, the integrative nature of the independent variables in representing the effects of competition (and other stresses) within pine stands makes the model a good first step in ranking the risk of SPB attack across landscapes.

Forest Health Monitoring field data were collected at forested locations in Alabama (n = 133), Georgia (n = 163), Maryland (n = 16), and Virginia (n = 106) on four circular subplots approximately 48 feet (14.46 m) in diameter and separated from one another by 120 feet (36.6 m) (Tallent-Halsell 1994). Live tree total and hardwood basal areas were computed for each subplot for 1995. Only plots with hardwood basal area/total basal area ratios of <50 percent were considered pine stands and used to compute the risk score. Radial growth was calculated for trees of southern pine species only by subtracting the 1991 diameter from the 1995 diameter and multiplying the result by 10/4 to put it on the 10-year basis required by the model. The SPB risk score for a plot location was assigned by taking the minimum value of the four computed subplot risk scores.

Figure 18 shows that south-central Alabama contains the highest proportion of plots exhibiting the highest degree of SPB susceptibility as defined by the model. These results parallel reports of actual SPB infested acreage. Alabama averaged 3.8 million acres of SPB outbreaks per year from 1991 to 1994, while neighboring Georgia exhibited an average affected acreage only 1/7 as large (Forest Pest Management 1995).

Figure 19 shows the proportion of FHM plots in each of the risk categories by State. Alabama, Georgia, and Virginia had the greatest proportion of plots in the low risk category. The proportion of plots in the high and moderate risk category for these three States also mirrors the sum of the total acreage affected by the SPB for the three States as published in Forest Pest Management reports (Forest Pest Management 1995).

A large SPB outbreak occurred in Virginia and Maryland in 1993. Although the SPB risk score was computed on only four FHM plots in Maryland, two of those four (or 50 percent) were classified as high risk. Historically, the eastern shore of Maryland exhibits the greatest tendency to SPB infestations. In Maryland in 1992 and 1993, 3,000 acres of SPB outbreak concentrated on the eastern shore[3]—the same geographic location that displays the highest risk of SPB susceptibility based on the computed risk scores.

Exotic Plant Species

Exotic species include vegetation, fauna, insects, fungi, viruses, and other organisms that are introduced into an ecosystem where they are not known nor suspected to have occurred in the past. Exotic plant species have a great potential to alter forest ecosystems and affect historic ranges of species composition and abundance. The influence of a new species can be devastating because evolution of an ecosystem may not have included the development of resistance strategies to this new influence.

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[3]Personal communication. 1996. Robert Rabaglia, Forest Pest Management, Maryland Department of Agriculture, 50 Harry S. Truman Parkway, Annapolis, MD 21401.

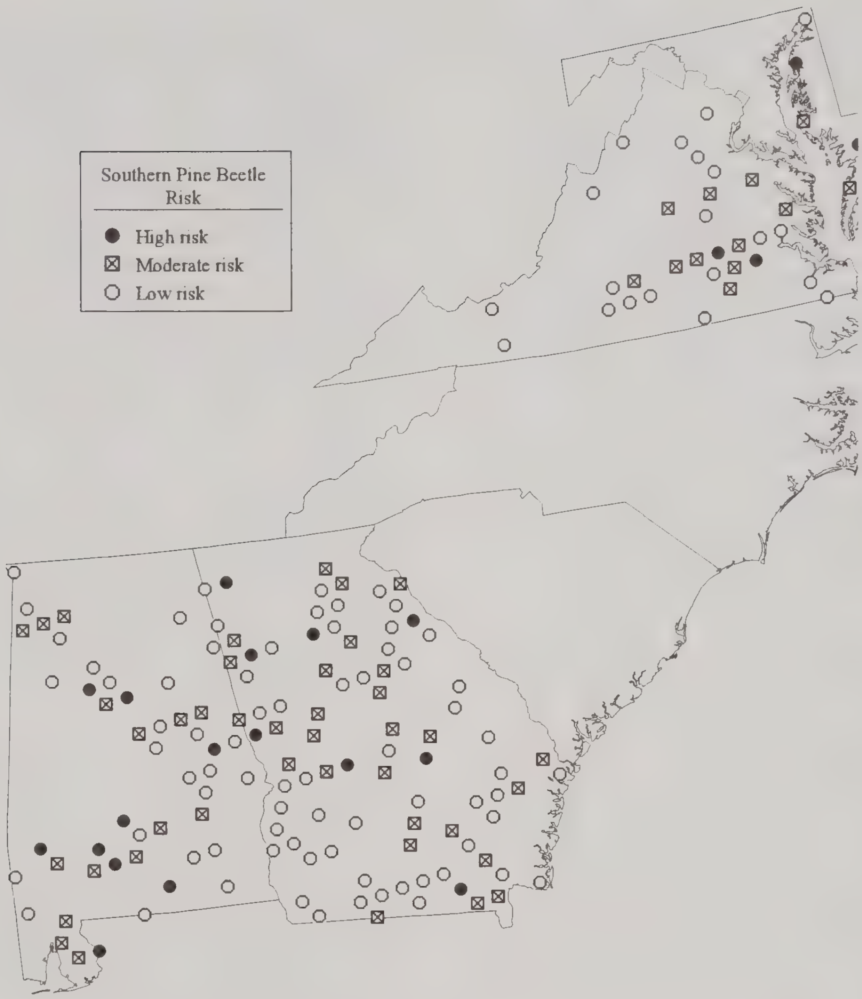

Figure 18—Spatial pattern of Southern Pine Beetle susceptibility for pine stands at Forest Health Monitoring field plot locations for Alabama, Georgia, Maryland, and Virginia.

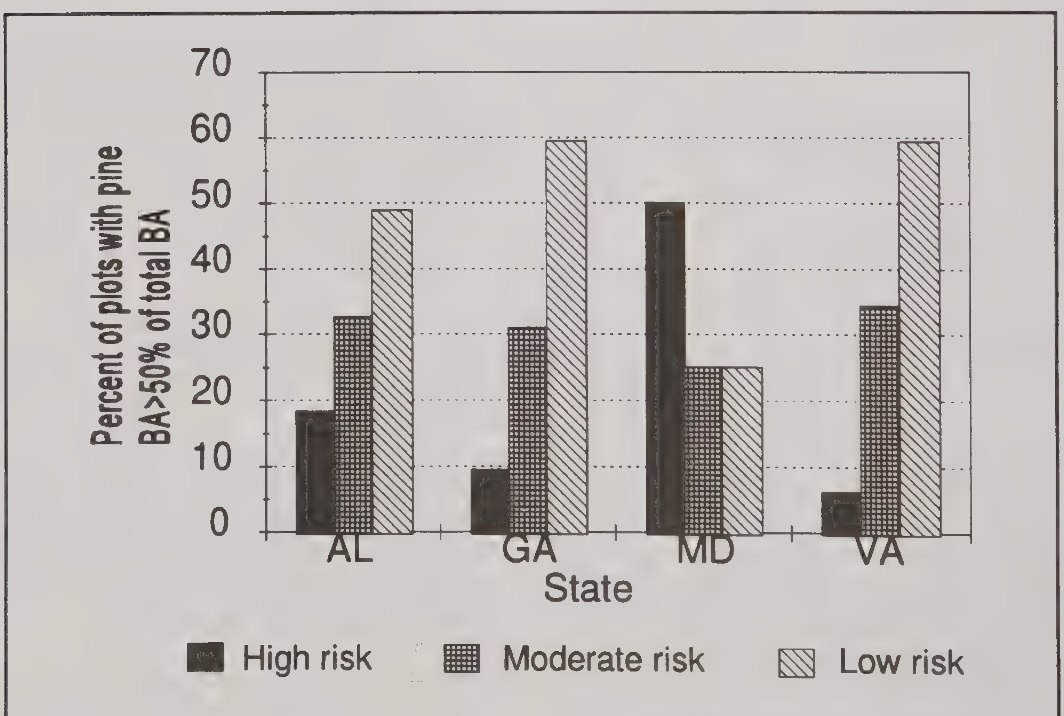

Figure 19—Risk class for southern pine beetle infestation in pine stands within four States having measured radial growth from the Forest Health Monitoring program (AL: n = 49; GA: n = 84; MD: n = 4; VA: n = 32).

As international travel and trade increase, the risk of introducing and spreading new exotic species increases. Many exotics are successful because they are able to move into disturbed areas. Information about amount and types of disturbance would provide useful data for risk assessment analyses. Other data, such as stand stocking levels and site quality, also aid in risk assessment for exotics that take advantage of disturbed or stressed ecosystems.

More quantitative and qualitative data in general may exist for eastern species than for western species. For example, national parks in the Southern Appalachian region list approximately 40 exotic plant species requiring control [Southern Appalachian Man and the Biosphere (p. 122) 1996b]. Because by definition the invasion of exotic plants implies that the species was not previously part of the ecosystem, the mere presence of an exotic species implies potential risk to the forest ecosystem.

The threat of exotic plant species to native vegetation is illustrated in a study by Stapanian and others.[4] As part of the FHM program, they collected plant diversity data on the ground stratum [0 to 0.6 m (0 to 2 feet) in height] vegetation from 279 plots in 18 States, grouped into 7 geopolitical regions (California, Colorado, Minnesota, parts of the Pacific Northwest, Southeast, mid-Atlantic, and Northeast). Their analysis looked at the frequency and abundance of exotic species, the influence of disturbance on the frequency of exotics, and the origin of the exotic species. The percentage of exotic species per region ranged from 13.5 percent in California to about 4.1 percent in Colorado (fig. 20). Although the proportion of exotic species was often relatively low, the cover of the exotic species was sometimes high; for example, exotics accounted for 25 percent of the understory cover in California (fig. 21). This observation suggests that in some regions of the United States, such as California, exotic plant species become relatively dominant in the understory. In the Southeastern United States, human-caused disturbances (e.g., prescribed burning, grazing, and logging) occurred on 59 percent of the plots, and these plots had a significantly higher proportion of exotic species than undisturbed plots. In some regions of the country, particularly the Western States, plots with human-caused disturbances did not contain significantly more exotic species than undisturbed plots, suggesting that microhabitat conditions were good for exotic colonization even without human-caused disturbance.

In general, exotic species in the Southeast tended to be of eastern and subtropical Asian origin. In the mid-Atlantic region, a number of exotic species were mainly western and temperate Eurasian, but the highest proportion of cover came from Asian species. In the remaining five regions, the exotic species were from western and temperate Eurasia. In general, the study by Stapanian and others (see footnote 4) suggests that the establishment and spread of exotic species is dependent on favorable microhabitats, which are sometimes, but not always, associated with human-caused disturbances.

[4] Stapanian, M.A.; Sundberg, S.D.; Baumgardner, G.A.; Liston, A. Exotic plant species composition and associations with anthropogenic disturbance in North American forests. Manuscript in review. Vegetation.

Fire

Fire has been a powerful, selective, regulatory mechanism in forest ecosystems for thousands of years. Fire alters ecosystems in the following ways:

- Removes overstory and understory vegetation,
- Exposes mineral soil, which provides a seedbed for regeneration but also increases the risk of erosion with resulting stream sedimentation,
- Releases nutrients and alters soil permeability,
- Triggers regeneration of serotinous seeds of some species, and
- Often improves wildlife habitat.

Altering natural fire cycles can have deleterious effects on forest ecosystems. When natural fires are suppressed, understory vegetation thrives (creating less desirable wildlife habitat and fuel ladders to upper canopy trees), duff covers potential seedbeds, and fuels accumulate eventually leading to catastrophic wildfires.

Fire or fire suppression affects all forest ecosystems on landscape scales. Fire suppression became a management tool in the early 1900's because death and destruction are associated with forest fires. Data on the number of acres burned exists within major Federal and State management agencies, including the USDA Forest Service, the Department of the Interior National Park Service, Bureau of Land Management, Fish and Wildlife Service, and all State forest groups. Data on the forest acres directly affected (burned) by fires are generally accurate. Areas of forest ecosystems, particularly length and area of aquatic systems affected by fires, are less well-known.

Fire statistics for the period January 1 to September 20, 1995, on the number of fires (table 8) and the number of acres burned (table 9) for various land management agencies and different regions of the country indicate the severity of fires in the Western United States, particularly the number of acres burned. Comparing the 1995 fire data with the 5-year average for the same regions indicates more fires in 1995 than the 5-year average, but less acres burned. The 5-year average does not include acres burned within the USDA Forest Service Southern Region for the autumn 1995 fire season (post-September).

Current trends are toward catastrophic fires covering large areas where fire suppression (e.g., Yellowstone fires) or harvesting of certain seral stages has resulted in accumulation of excess fuels. Because suppressing fires

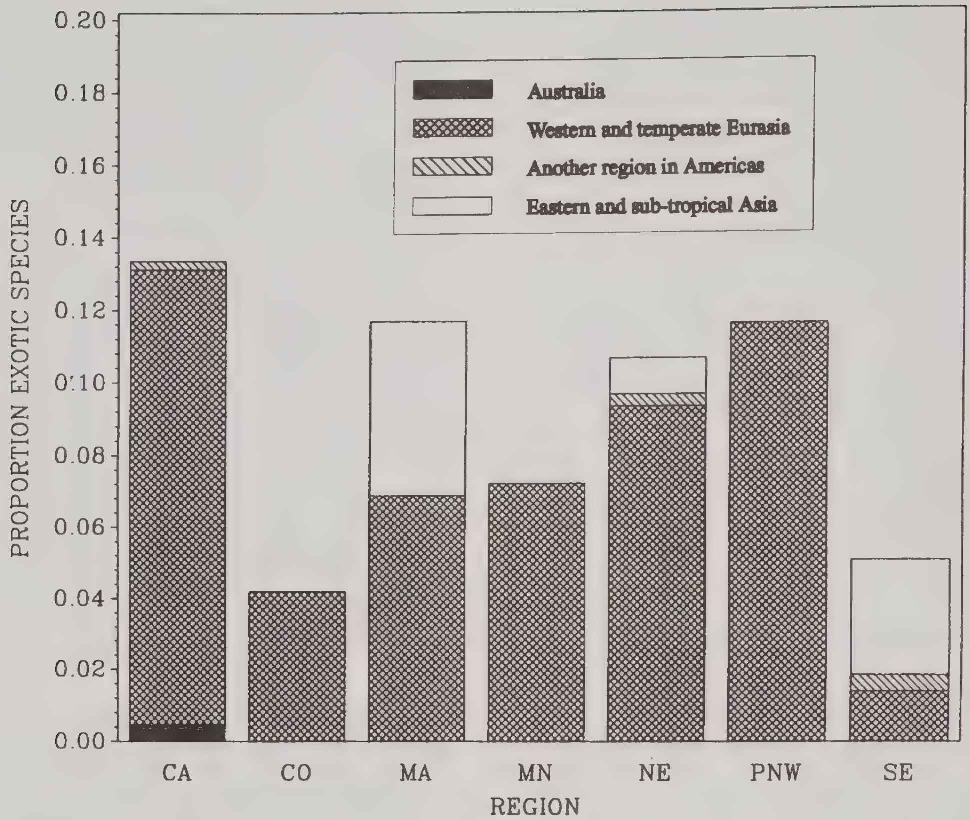

Figure 20—Proportion of total number of exotic species in the understory ground stratum (0 to 0.6 m) found on 279 FHM plots in seven geopolitical regions of the United States (CA = California; CO = Colorado; MA = Mid-Atlantic; MN = Minnesota; NE = Northeast; PNW = parts of Pacific Northwest; SE = Southeast).

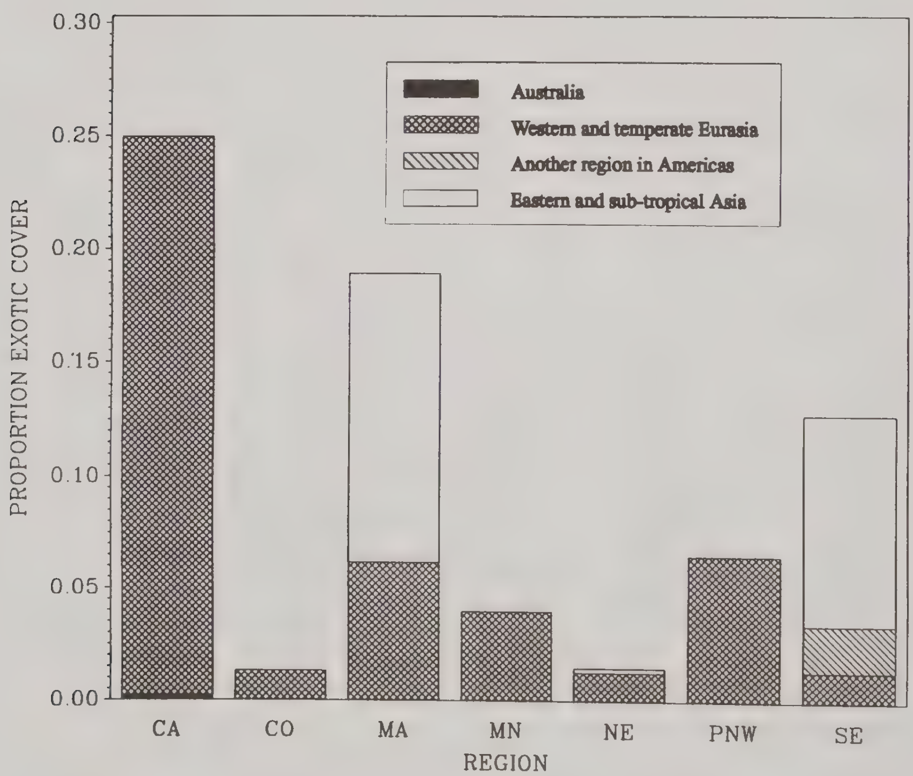

Figure 21—Proportion of total canopy cover of exotic species in the understory ground stratum (0 to 0.6 m) found on 279 FHM plots in seven geopolitical regions of the United States (CA = California; CO = Colorado; MA = mid-Atlantic; MN = Minnesota; NE = Northeast; PNW = parts of Pacific Northwest; SE = Southeast).

Table 8—Number of fires from January 1 to September 20, 1995

Area	Bureau of Indian Affairs	Bureau of Land Management	Fish & Wildlife Service	National Park Service	States	USDA Forest Service	Total
Alaska	2	25	13	4	317	6	367
Northwest	251	319	2	35	1,596	1,031	3,234
CA-Northern[a]	106	33		37	1,634	557	2,367
CA-Southern[b]	9	209		5	1,634	512	2,369
Northern	217	71	6	25	417	631	1,367
GB-Eastern[c]	28	538		19	406	859	1,850
GB-Western[d]		370			66	100	536
Southwest	1,781	345	15	168	1,342	1,935	5,586
Rocky Mtn	475	502	1	52	660	371	2,064
Eastern	343			87	14,309	562	15,301
Southern	10		58	92	38,922	1,069	40,151
Total USA	3,222	2,412	95	524	71,303	7,636	85,192
Average (1990-1994)[e]							61,160

[a] California-Northern.
[b] California-Southern.
[c] Great Basin-Eastern.
[d] Great Basin-Western.
[e] Does not include acres for fall fire season (Sept. 21–Dec. 1) within USDA FS Southern Region.

Table 9—Number of acres burned from January 1 to September 20, 1995

Area	Bureau of Indian Affairs	Bureau of Land Management	Fish & Wildlife Service	National Park Service	States	USDA Forest Service	Total
Alaska	90	18,947	3,709	1,595	19,048	1	43,390
Northwest	626	42,131	2,700	21	4,684	7,227	59,389
CA-Northern[a]	59	2,840		375	7,015	3,004	13,293
CA-Southern[b]	163	69,767		5,830	7,015	12,362	95,137
Northern	8,158	2,952	533	15	3,306	1,945	16,909
GB-Eastern[c]	258	362,170		212	53,407	8,046	424,093
GB-Western[d]		100,730			3,067	11,917	115,714
Southwest	54,743	69,387	1,107	13,363	75,539	87,303	301,442
Rocky Mtn	5,497	8,762	1	174	2,518	9,257	26,209
Eastern	5,322			1,462	174,068	17,798	198,650
Southern	111		11,836	11,937	325,147	33,284	382,217
USA	74,927	679,686	19,886	34,984	674,777	192,144	1,676,404
Average (1990-1994)[e]							2,786,662

[a] California-Northern.
[b] California-Southern.
[c] Great Basin-Eastern.
[d] Great Basin-Western.
[e] Does not include acres for fall fire season (Sept. 21–Dec. 1) within USDA FS Southern Region.

beyond the expected natural variation based on historical records continues in many forests in both the Eastern and Western United States, fuel accumulation above historic ranges is expected to continue. This fuel buildup in forest ecosystems will be exacerbated by tree mortality from exotic and endemic insect and disease activity. Prescribed burning efforts are moving the forests toward more natural cycles, which will eventually lead to fewer, smaller fires, creating the desired mosaic of different aged stands.

To improve the ability to estimate fire risk (both frequency and intensity of fires), inventory and monitoring data are needed on biological factors such as fuel loading, basal area/unit area, species population density, and management practices. In addition, information on environmental factors such as climate, topography, soil moisture, and drought cycles would improve the ability to predict areas of the country at highest fire risk. For example, the combination of old, heavily stocked stands and drought generally equals a high risk for catastrophic fires. Additionally, evaluating whether post-fire forest stands are overstocked from natural or planted revegetation would indicate potential problem areas of the future.

The information needed to estimate fire risk can be obtained through a combination of ground monitoring and remote sensing. Ground monitoring information is needed to assess the type, biomass, and structure of the vegetation. Table 10 lists the types of variables required to evaluate the risk of flammability and indicates whether the variables are currently recorded in the FHM program. The FHM program collects many variables that could be used to estimate flammability risk, but more are needed. Remote sensing could be used for some direct measurements and for extrapolation of data from a limited number of field plots to large, landscape scales. Ground and remote sensing data could be used in combination to consider risk factors and assess risk. Forest health could also be assessed using models based on ground and remote sensing data.

Air Pollution

Since the industrial revolution, air pollutants have shown the potential to cause minor to severe impacts on forest ecosystems (Innes 1993, Olson and others 1992, Smith 1981). Before the advent of pollution controls, uncontrolled smelters, power plants, and other pollutant-producing sources caused significant

Table 10—Data requirements for fuel-loading models and flammability assessments

Data required	Forest Health Monitoring as data source
Fuel loading (Missoula fire lab index)	Grass (cover and depth)[a] Shrub (cover and depth)[a] Slash (cover and depth)[a] Litter (cover and depth)[a]
Biomass accumulation index	
Understory	Vegetation diversity/cover
Overstory	Tree basal area, crown cover
Stand age (> 40 years at risk)	Site tree and stand age
Species composition	Diversity of overstory, midstory, and understory microplot cover, forest type
Stand structure	Tree spacing, size, and height Crown class, tree history
Drought potential	Palmer Drought Index[b]
Soils (erosion and fertility)	Litter depth/cover, carbon and nitrogen pools
Habitat groups (Based on temperture/moisture regimes)	Condition class, forest types Site slope and aspect
Intervals between fires	Tree mortality–year and cause Interim and past disturbance

[a] Currently cover, but not depth, is measured or estimated in the FHM program.
[b] Data from the National Oceanic and Atmospheric Administration (NOAA).

damage to portions of forest ecosystems. The extent of the damage was related to the size of the source. The damage severity was often very high near the source; when all vegetation was removed and soil was eroded down to parent material, that portion of the forest ecosystem essentially reverted back to a stage of primary succession. Today, the most significant threats to forest ecosystems come from the regional deposition of ozone, nitrogen, sulfur, and hydrogen ion.

Plant species (vascular and nonvascular) and soil analysis can be used to estimate the percentage of forest ecosystems affected by air pollutants. For example, ozone has caused visible foliar injury to vegetation (herbs, shrubs, and/or trees) in many forests in the West, Great Lakes States, and East. In California, ozone has reduced needle retention, tree growth, and resistance to bark beetles and increased susceptibility to drought (Miller 1992). The relationships between visible foliar injury and reductions in growth, increased susceptibility to pathogens, and reduced progeny are still being discovered.

The deposition of atmospheric nitrogen in a forest ecosystem, acting as a fertilizer, might be considered a positive impact if the purpose of that ecosystem is to produce wood volume. Nitrogen fertilization can also affect the abundance and distribution of species and reduce biodiversity by favoring nitrophilus species. In addition, nitrogen saturation of the soil can occur, with subsequent acidification of the soil and loss of important cations, and nitrogen compounds can cause acidification of precipitation with subsequent effects on foliar and soil chemistry.

Sulfur, like nitrogen, can cause acidification of precipitation and soil and loss of important cations. Sulfur compounds are also known to be highly and directly phytotoxic to vascular plants and, especially, to some lichen species. Excess hydrogen ions, or lowering of pH in precipitation and in soils, generally leach important cations from foliage and soils and mobilize other undesirable cations like aluminum.

The effects of air pollution on forest ecosystems are evaluated regionally in the FHM program in three ways: ozone bioindicator plant evaluation;[5] lichen community analysis focusing on sulfur and nitrogen sensitive species[6]; and soil chemistry analysis evaluating soil pH and exchangeable Ca, Mg, and K.[7] Lewis and Conkling[8] provide details of each method. Currently in the FHM program, the implementation of the ozone bioindicators in the East and Great Lakes States is well developed; implementation of lichen and soil chemistry indicators has been done only in limited areas in the Southeast and West.

Ozone bioindicator plants are vascular plant species (herbs, shrubs, or trees) that are highly sensitive to ozone air pollution and respond with distinct foliar injury symptoms that can be diagnosed under field conditions. Ozone bioindicator plants are evaluated on or near the FHM plots where the appropriate ozone-sensitive plant species are found. Plots are scored as positive or negative for ozone injury. The severity of ozone injury at each plot is also recorded (see footnote 5).

Lichen community field procedures include collecting macrophytic lichens from woody substrates on the FHM plots. The FHM crews are trained to collect a sample of each species found and record the relative abundance of each species. The actual species identification is done by lichen experts. In this report, the air quality scores from plots in the Southeast United States are discussed. The air quality scores are based on models developed from analysis of lichen communities along established sulfur and nitrogen air quality gradients (see footnote 6).

Soil chemistry focuses on key components of the soil that air pollutant deposition will probably affect first. As with lichens, trained FHM crews collect samples and make basic horizon depth measurements. The chemical analyses are performed by laboratories specializing in this field. This report presents the spatial patterns of mineral soil pH and total soil carbon from plots in the Southern Appalachian area of the Southeastern United States.

The spatial pattern of ozone injury in the Northeast, mid-Atlantic, and Great Lakes States indicates distinct areas where tropospheric ozone injures forest plant species (fig. 22). Plots in southern Vermont, Maryland, Pennsylvania, and parts of the Great Lakes States were positive for injury, whereas most of Maine, West Virginia, and Minnesota were negative for injury.

The spatial pattern of lichen air quality scores at plots in the Southeastern United States indicates air quality is generally better along the coastal areas of Georgia, South Carolina, and North Carolina than the mountainous areas of these States, as well as Tennessee and Virginia (fig. 23). Air quality at most plots in Virginia was relatively poor throughout the State.

The spatial pattern of mineral soil pH in the Southern Appalachian region indicates no distinct patterns but does suggest that many plots have relatively low pH values (fig. 24). These values may be representative of normal,

[5] Smith, G.C.; Brantley, E. Bioindicator plants. In: Lewis, T.E.; Conkling, B.L., eds. Forest health monitoring indicators of forest health: indicator development research. Chapter 5. Manuscript in preparation.

[6] McCune, B.M.; Dey, J.; Peck, J. [and others]. Lichen communities. In: Lewis, T.E.; Conkling, B.L., eds. Forest health monitoring indicators of forest health: indicator development research. Chapter 11. Manuscript in preparation.

[7] Hudson, B.D.; Van Remortel, R.D. Soil morphology and chemistry. In: Lewis, T.E.; Conkling, B.L., eds. Forest health monitoring indicators of forest health: indicator development research. Chapter 15. Manuscript in preparation.

[8] Lewis, T.E.; Conkling, B.L., eds. Forest health monitoring indicators of forest health: indicator development research. Manuscript in preparation.

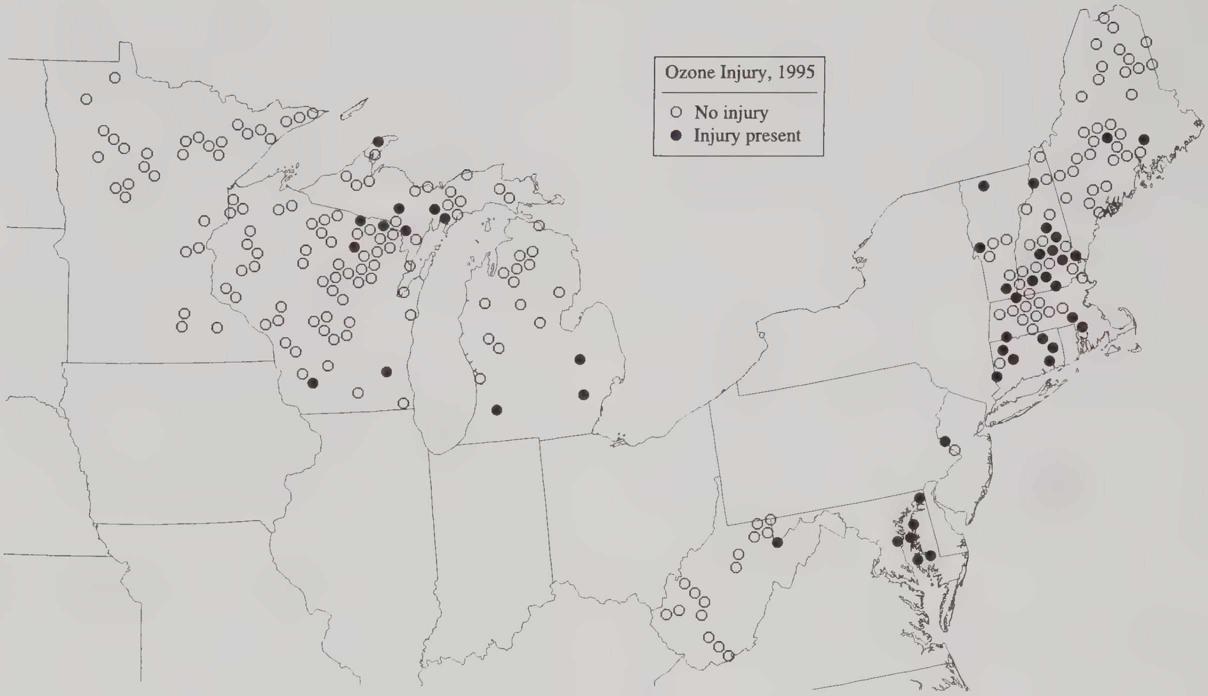

Figure 22—Spatial pattern of ozone injury in 1995 in the Northeast, mid-Atlantic, and Great Lakes States.

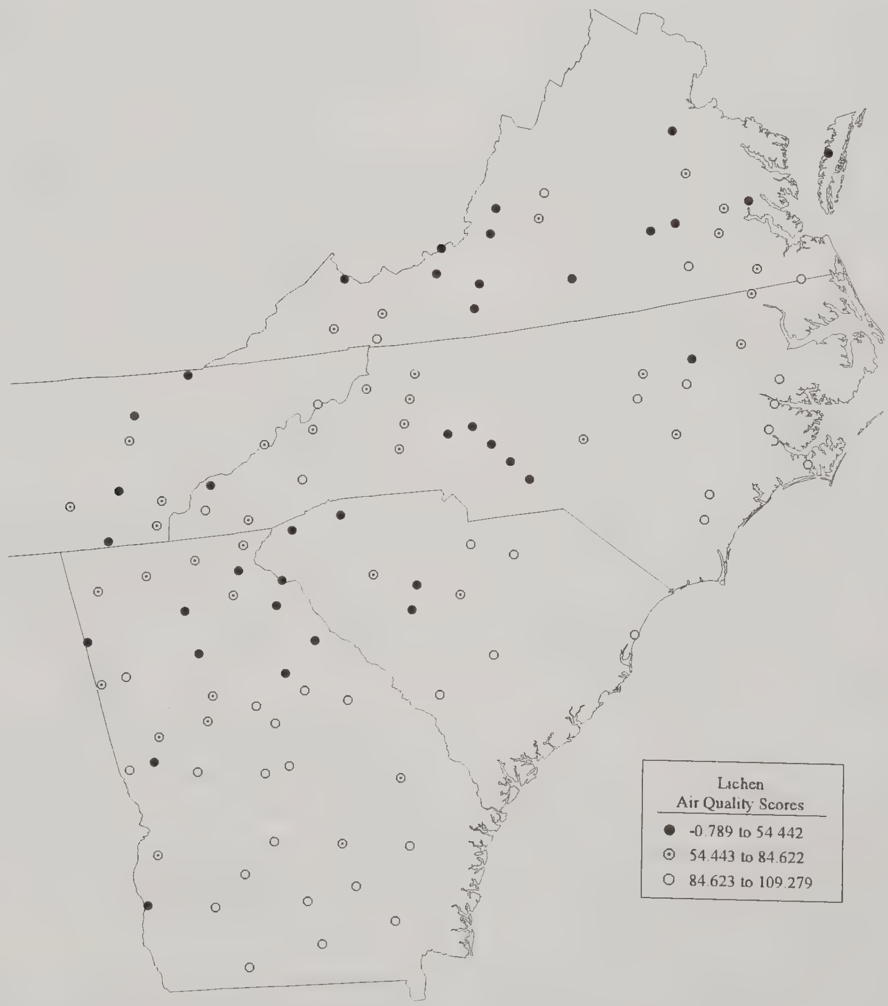

Figure 23—Spatial pattern of lichen air quality scores in 1992 and 1993 in the Southeast U.S. Higher numbers (open circles) indicate better air quality.

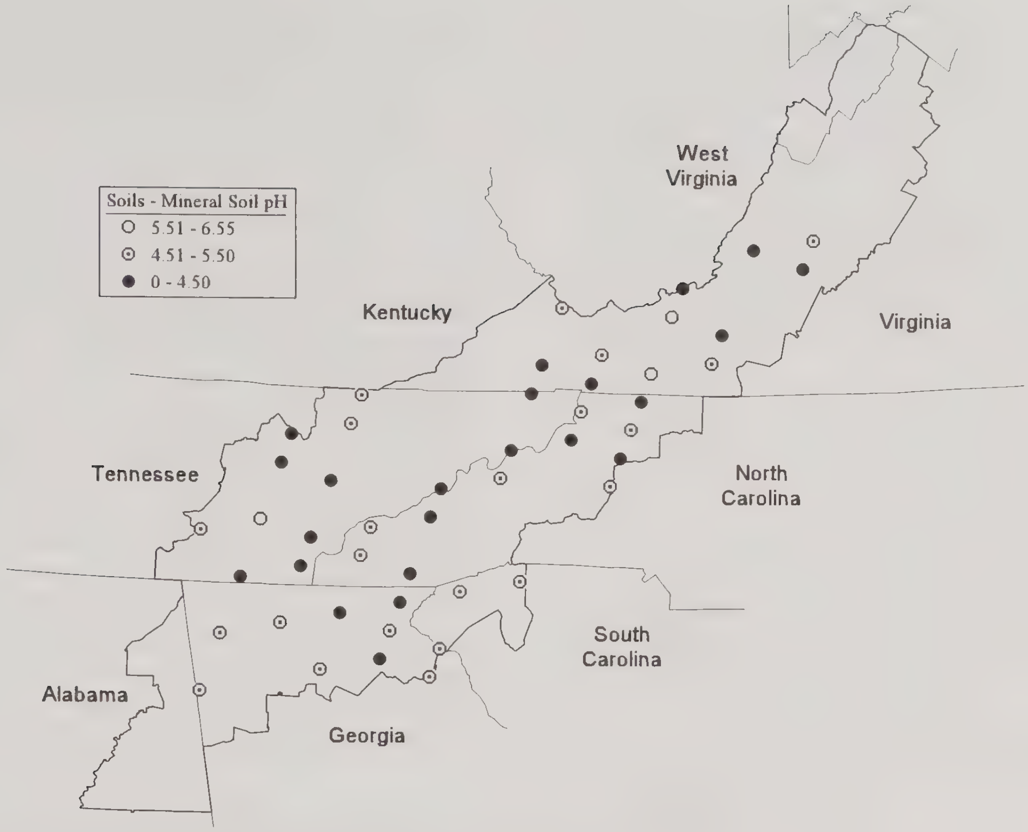

Figure 24—Spatial pattern of mineral soil pH in the Southern Appalachian region.

expected ranges dependent on local parent material, type of vegetation growing on the site, and other site factors.

Air pollution appears to affect forest vegetation to varying degrees, depending on local conditions. The spatial patterns of injury to forest vegetation from air pollutants generally reflect the distribution of deposition of relevant air pollutants in these regions (Shadwick and Smith 1994, Southern Appalachian Man and the Biosphere 1996a). Even though elevated ozone concentrations might occur over large regions in the Eastern United States, injury to vegetation appears to be more localized in areas where higher ozone concentrations occur at sites with environmental factors, such as soil moisture and relative humidity, conducive to the uptake of ozone.

Important Ecosystem Process—Red and Black Oak Regeneration

The regeneration of key species is a vital process in sustaining certain forest communities. Northern red oak and black oak are valuable Southern Appalachian tree species that have difficulty succeeding as dominants in the overstory after disturbance, especially on the highest quality sites where tulip poplar and red maple are often aggressive competitors (Kellison 1993). The decline in northern red oak regeneration on high sites in the Southern Appalachian region has been a concern for several decades (McGee 1967). Steady increases in N. red oak stumpage prices over the last 20 years have heightened the awareness of the problem (Kellison 1993).

Successful oak regeneration depends on establishing adequate advanced oak seedling and sapling regeneration of a suitable size [>4.5 feet (1.37 m) in height] and root development (Clark and Watt 1971). The reduction of historic and prehistoric patterns of frequent disturbances in the Southern Appalachian region (i.e., grazing, fire, logging) may exacerbate the regeneration problem (Carvell and Tryon 1961, Crow 1988).

Successful oak regeneration is an important issue in the Southern Appalachian region and other regions where oak is an important component of the forest (Clark 1993). Oak mast is a mainstay of wildlife populations, and oak wood properties have long made oak species preservation an economic concern. The continued spread of the gypsy moth into the Southern Appalachian region has the potential to damage the existing oak overstory component.

Appalachian oak forests extend throughout the Southern Appalachian region (Stephenson and others 1993). The basic mensuration data presented in this section were collected by the FHM program from 1991 through 1994 from 146 plots sampled in the Southern Appalachian region. Oak species (especially chestnut oak) were the most prevalent tree species tallied.

The oak regeneration problem is most acute on mesic sites in the Southern Appalachian region. Trees of oak species were separated into two groups, northern red and black oaks (*Quercus rubra* and *Q. velutina*) and all other oaks (*Q. prinus, Q. stellata, Q. coccinea,* etc.), which represent mesic and xeric site conditions, respectively. Table 11 shows the frequency of N. red and black oaks (more mesic sites) and all other oaks (more xeric sites). The probability of these sites becoming oak stands after overstory disturbance was based on on-site advanced regeneration counts on 125 plots. No oak trees were found in 21 plots.

The probability of a future oak stand resulting from overstory disturbance was assigned conservatively by computing advanced regeneration as the number of oak trees per acre in the 1- to 5-inch (2.5 to 12.7 cm) diameter class. Oak regeneration studies in the Southern Appalachian region suggest that approximately one of every three oaks in this size range will become a dominant or codominant tree by age 20 after overstory disturbance (Loftis 1993). Loftis (1993) also includes seedlings less than 1 inch (2.5 cm) in basal diameter, but their probability of becoming dominants or codominants in the overstory is an order of magnitude less than the 1- to 5-inch (2.5 to 12.7 cm) diameter range.

The highest probability class was assigned to sites that had at least 300 oaks per acre tallied as 1 to 5 inches (2.5 to 12.7 cm) in diameter. The medium probability class was assigned to plots having 1 to 300 oaks per acre in the 1- to 5-inch (2.5 to 12.7 cm) diameter range and the lowest probability class was assigned to plots with no oak seedlings or saplings tallied in the understory. Figures 25 and 26 show the pattern of these probability classes.

The pattern of probability classes for N. red and black oaks shows that most mesic oak sites with no advanced regeneration occur in the northern area of the Southern Appalachian region (fig. 25). Most sites with the highest probability of maintaining dominant N. red and black oaks in the overstory after disturbance (>300) also occur in this area. In contrast, the pattern of more xeric oak sites shows the concentration of the highest and lowest probability sites in the southern portion of the Southern Appalachian region (fig. 26).

Plant Biodiversity

Biological diversity can be considered at three levels: ecosystem, community, and individual species. All three levels are interconnected and hierarchial; species are dependent on communities, which are dependent on the larger ecosystems in which they reside. Loss of species can, however, sometimes affect higher levels of organization. For example, loss of the once common American chestnut in the Eastern United States has affected many floral and faunal components of oak-hickory forests. Biological diversity is important at all levels, not only for consideration of individual species, but for the integrity of communities and ecosystems. Because one consistent response of all ecosystems to a variety of stressors is loss of species diversity (Rapport and others 1985), change in species diversity is an early indication of stress to the ecosystem.

Vegetation species are an important component of biodiversity. Based on fossil records, however, many more millions of species have become extinct than exist in total today. As conditions change and habitats are altered, species become extinct. Therefore, the normal variation in extinction, suggested by the fossil record, must be compared to the major forces of human-influenced change that lead to species extinction (for example: climate, fire, and management). Species extinction may be higher than historic variation because human activities add another stress to natural forces, such as change in climate.

Species diversity is based on the number and abundance of species. Number refers to the quantity of individual taxa, while abundance is usually quantified by number, size/cover of species, or both. While numerous indices

Table 11—Numbers of sample locations classified by their probability of sustaining oak dominants and codominants in the overstory 20 years after disturbance

Probability classes	More mesic sites N. red and black oaks	More xeric sites Other oak species
High probability of becoming an oak dominant-codominant stand by age 20	6	4
Medium probability of becoming an oak dominant-codominant stand by age 20	30	12
Lowest probability of becoming an oak dominant-codominant stand by age 20	26	47
Totals	62	63

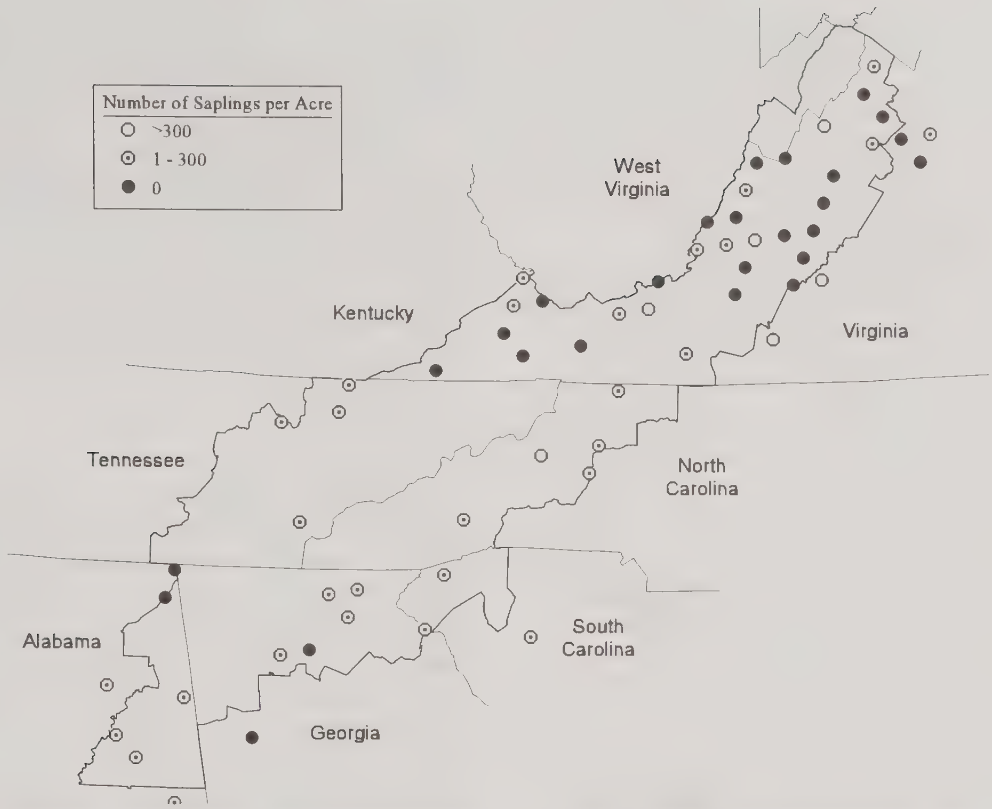

Figure 25—Spatial pattern of number of saplings per acre for northern red and black oak regeneration on mesic sites, which had overstory oaks on the plot. Classes of number of saplings correspond to the probability that the stand will be oak dominant-codominant by age 20.

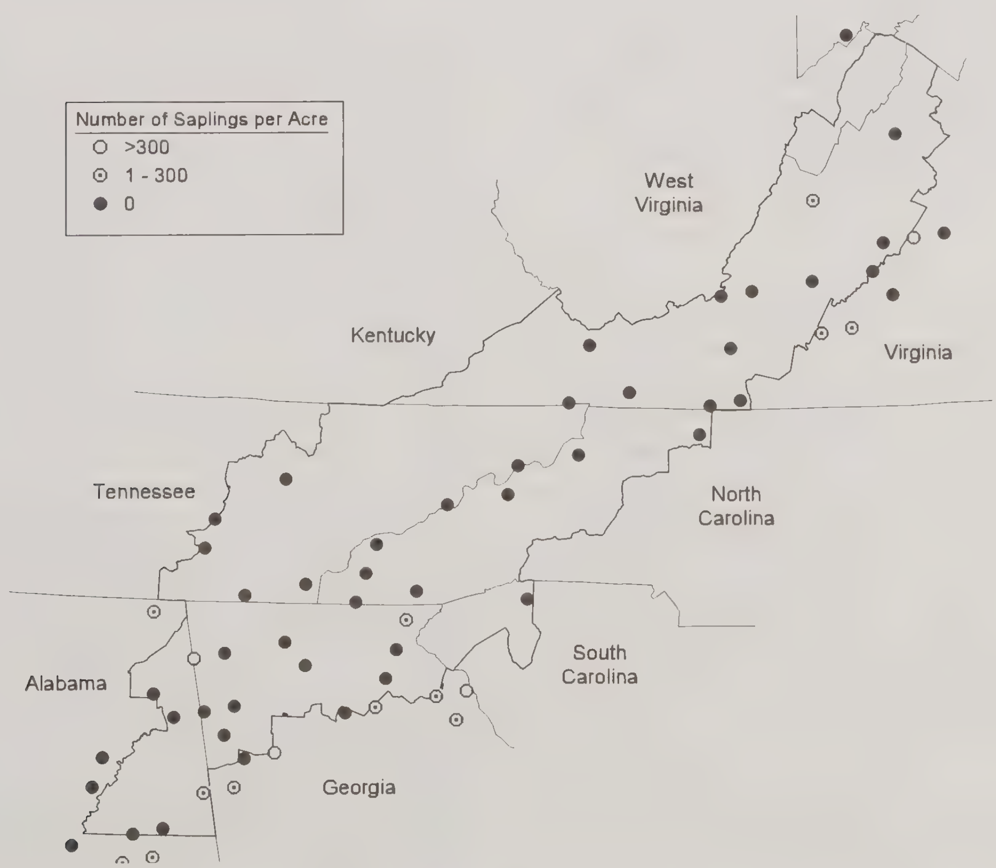

Figure 26—Spatial pattern of number of saplings per acre for oak regeneration on xeric sites, which had overstory oaks on the plot. Classes of number of saplings correspond to the probability that the stand will be oak dominant-codominant by age 20.

evaluate the combination of species number and abundance, two basic indices are species richness (number of species) and species evenness (relative abundance of species).

The spatial patterns of vascular species diversity were evaluated in the Southern Appalachian region in 1992 and 1993 as part of a regional demonstration study. The vascular plant diversity was measured as follows: understory (grasses, herb, shrubs) in three 1-m^2 quadrats in each subplot (168.3 m^2); midstory (large shrubs, small trees, and sapling trees) in the microplot (13.5 m^2) of each subplot; and overstory [trees >5 inches (12.7 cm) diameter at breast height (dbh)] in each subplot that comprise an FHM plot (Bechtold and others 1995). Plants are identified to the species level, and the abundance of each species is quantified (Stapanian and Cline 1995).

In the FHM program, field crews trained to differentiate between species and to quantify the relative abundance of each species evaluate the diversity and abundance of macrophytic lichen species on woody substrates. Samples of each species are mailed to a lichen expert for species identification. This report examines the richness of lichen species in the Southeastern United States in 1992 and 1993 and in the Northeast and Great Lakes area in 1994.

The spatial patterns of vascular species richness in the Southern Appalachian region in 1992 and 1993 indicate a wide range of values across the region. Many plots have relatively few species in any strata (fig. 27). Similarly, lichen species richness is highly variable but is highest in some of the mountainous regions of the Southeast in 1992-93 and in the northern New England and Great Lakes States areas in 1994 (fig. 28).

Soil Conservation

Soils are a key element of healthy forest ecosystems. Plants obtain water and nutrients from the soil, and most of the crucial mineral exchange between the biosphere and the inorganic world occurs in the soil (Ricklefs 1979). When plants die, they decompose and mineral nutrients return to the soil. The numerous bacteria, fungi, minute arthropods and worms, termites, and millipedes responsible for decomposition are abundant in the surface layers of the soil where dead organic matter is most plentiful. The activities of these organisms contribute to the development of soil properties from the surface down, whereas physical and chemical decomposition of the bedrock contribute to soil development from below.

Whether a forest ecosystem is healthy or at risk relative to the soil component can be based on the evaluation of three soil criteria: degree of soil stability and watershed function; integrity of nutrient cycles and energy flows; and the presence of functioning recovery mechanisms. Hudson (1995) inferred from other analyses of the estimated extent of human-induced soil degradation on a global basis that the primary threats to soil stability in forest ecosystems are erosion by water, acidification, loss of nutrients, and compaction.

The FHM program recognizes that most of the soil volume is relatively inert, and most of the chemical and biological functions in soil are related to clay and organic matter (Hudson 1995). Therefore, FHM focuses on the biological, chemical, and physical processes of clays and organic matter in the upper 50 cm (20 inches) of soil, with most emphasis on the upper 20 cm (8 inches).

Soil Erosion

Soil stability is one criterion for a sustainable, healthy soil system and is a prerequisite for meeting the criteria of nutrient cycling and functioning recovery mechanisms (see footnote 7). Variation in soils is determined by five factors: climate; parent material; vegetation; local topography; and, to some extent, age of the soil. Once formed, soils remain in a state of flux although they frequently obtain regionally characteristic steady-state properties. The process of soil formation can be drastically altered by soil erosion. Steep rock faces are examples where erosional forces are greater than the processes that lead to soil formation and buildup. The process of soil formation and buildup usually takes many years in temperate climates, and steady-state conditions must be protected from disturbance by soil erosion.

Standard technical definitions characterize soil erosion and classes designating extent. Surface erosion of soil is the removal of the soil surface by water, wind, ice, or other processes (Warrington and others 1980). Surface soil loss by water specifically involves the detachment of mineral soil particles and organic material from the soil surface. The energy for soil particle detachment by water can come from rainfall impact and shear from flowing water if a low vegetative canopy and a mineral or organic surface mulch are not present to help mitigate these effects.

The erosion rate on undisturbed forest land is very low. An increase in the extent of areas with accelerated erosion is evidence of increased ecosystem disturbance. The following factors likely increase the risk of soil erosion in forests: reduction of the overstory canopy; removal or alteration of the understory vegetation; disturbance or reduction (or both) of the litter layer; creation of bare soil areas; creation of channels; loss of plant litter cover and creation of hydrophobic soil conditions after fire; and changes in the soil mineralogy that reduce soil wetability. Examples of human activities that affect these factors are road construction for logging and mining, destruction of forest floor by frequent human-caused fires, and soil compaction from domestic animals grazing.

Most models developed in the first half of this century calculated soil loss from agricultural lands. The most

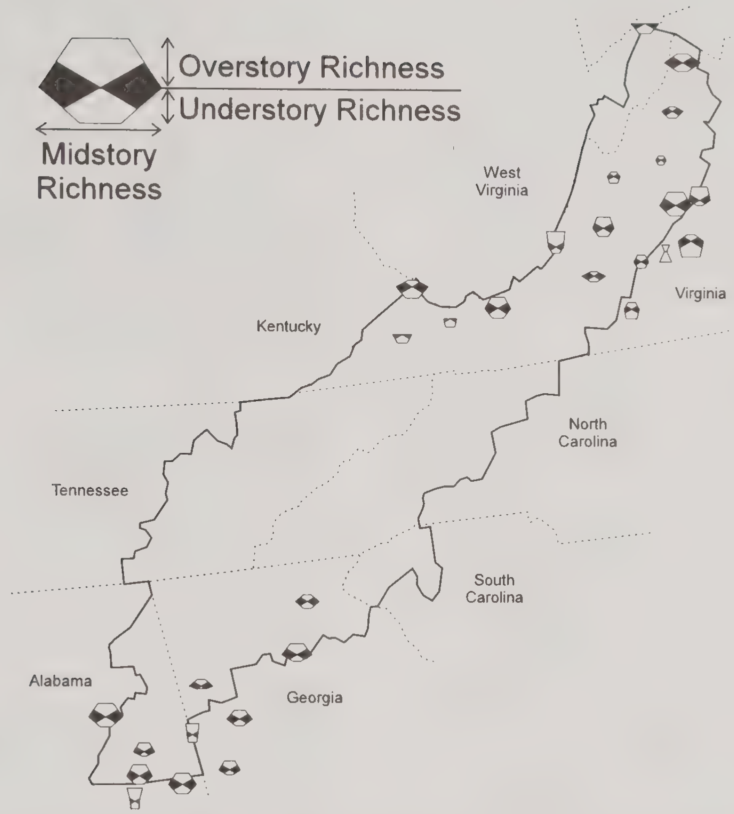

Figure 27—Spatial pattern of vascular species richness in 1992 and 1993 in the Southern Appalachian region.

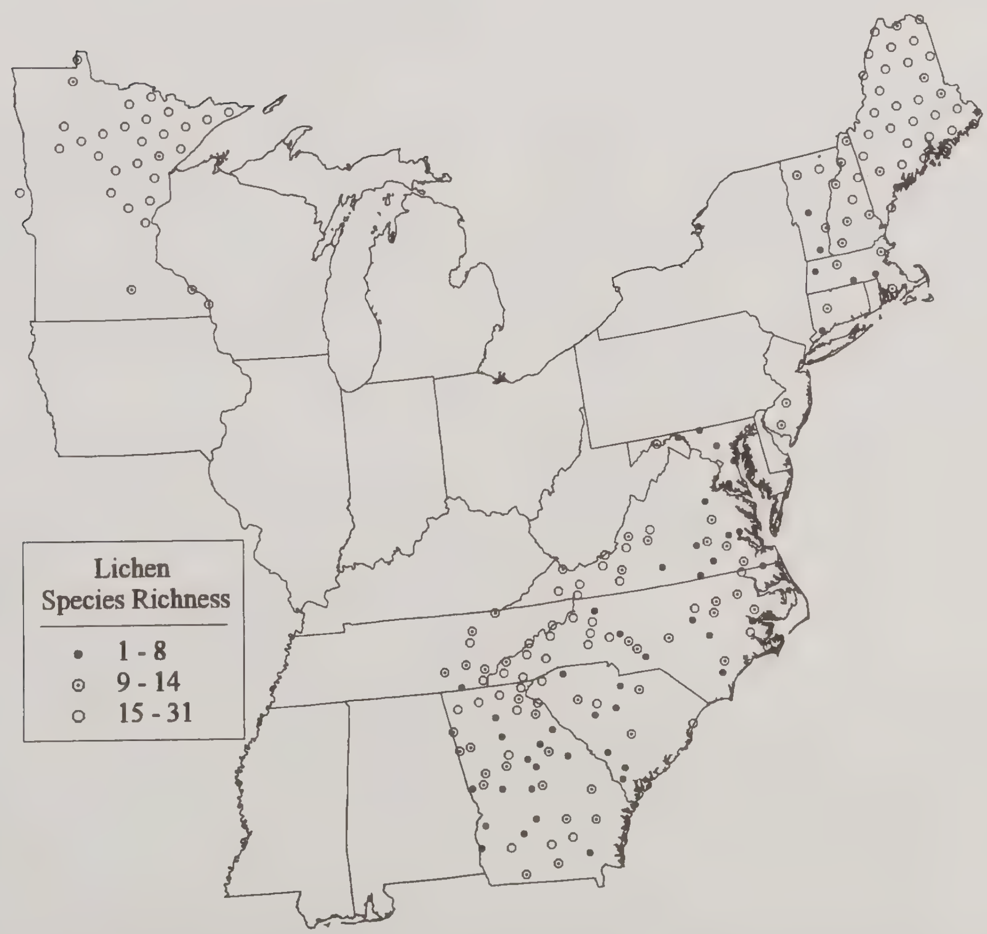

Figure 28—Spatial pattern of lichen species richness in 1992 and 1993 in the Southeast U.S. and in 1994, in the Northeast U.S. and Great Lakes States area.

acceptable model for estimating surface soil erosion on agricultural land is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965). Development of a similar model for forests has led to a Modified Soil Loss Equation. In this model, the cropping management factor and the erosion control practice factor in the USLE have been replaced by a vegetation-management factor. This erosion model provides a long-term estimate or an index of the amount of soil loss from a given site (Wischmeier 1976).

The thickness of the forest litter layer, duff, or O horizon is measured at three points between the four FHM subplots (see footnote 7). A small sample hole [area 0.3 m^2 (3 $feet^2$) and maximum depth 30 cm (12 inches)] is dug and the depth of the O horizon is calculated as the mean of four O horizon depths measured at the four cardinal compass directions. The overall depth of the O horizon at the plot level is the mean of 12 measurements taken at three points. The thickness of the mineral surface layer, or A horizon, is measured at the four cardinal compass points as the depth between the O horizon and the subsoil, or B horizon. These sampling methods were used on FHM plots in parts of the Southeastern United States as part of FHM sampling protocol development, and data from the plots in the Southern Appalachian region were analyzed as part of that study (Southern Appalachian Man and the Biosphere 1996b).

Analysis of the O horizon thickness indicates that litter depths in many sites in the Southern Appalachian region are relatively thin (fig. 29). Few sites had litter depths exceeding 5.0 cm (2 inches). No spatial pattern was apparent in the distribution of these litter depths.

A horizon thicknesses in many sites in the Southern Appalachian region were also relatively thin, with few sites having A horizons exceeding 20.1 cm (7.9 inches) (fig. 30). Again, no spatial pattern was apparent in A horizon thicknesses on the plots.

The depth of the A and O horizons on FHM plots in the Southern Appalachian region is relatively shallow. Based on numerous reports of excessive erosion in the Southern Appalachian region from management practices early in this century (see footnote 7), this observation could be expected.

Soil Fertility

Forest ecosystems recycle most of their nitrogen, phosphorus, and other nutrients through the soil. Soil organic matter is also a major component in the global carbon cycling, and its condition strongly reflects ecosystem disturbance because it is usually concentrated at the soil surface. Sufficient data are not available to make reliable estimates of soil organic matter in most regions.

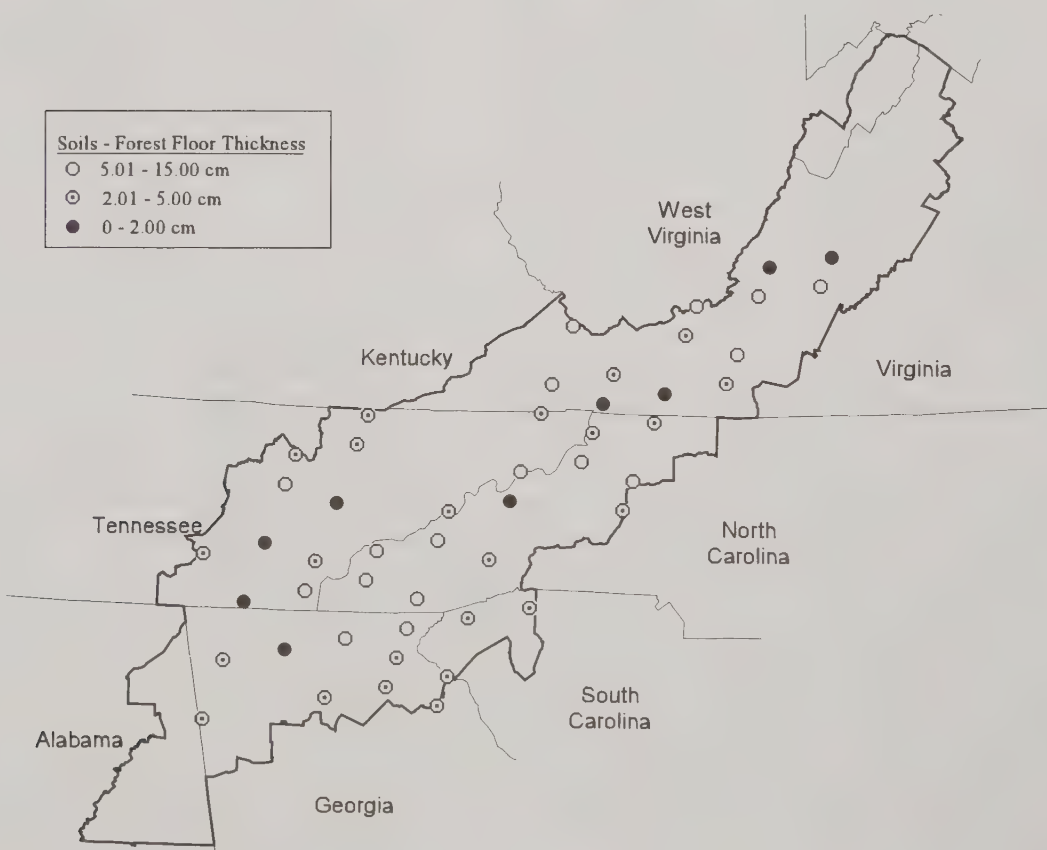

Figure 29—Spatial pattern of forest floor (O Horizon) thickness in the Southern Appalachian region.

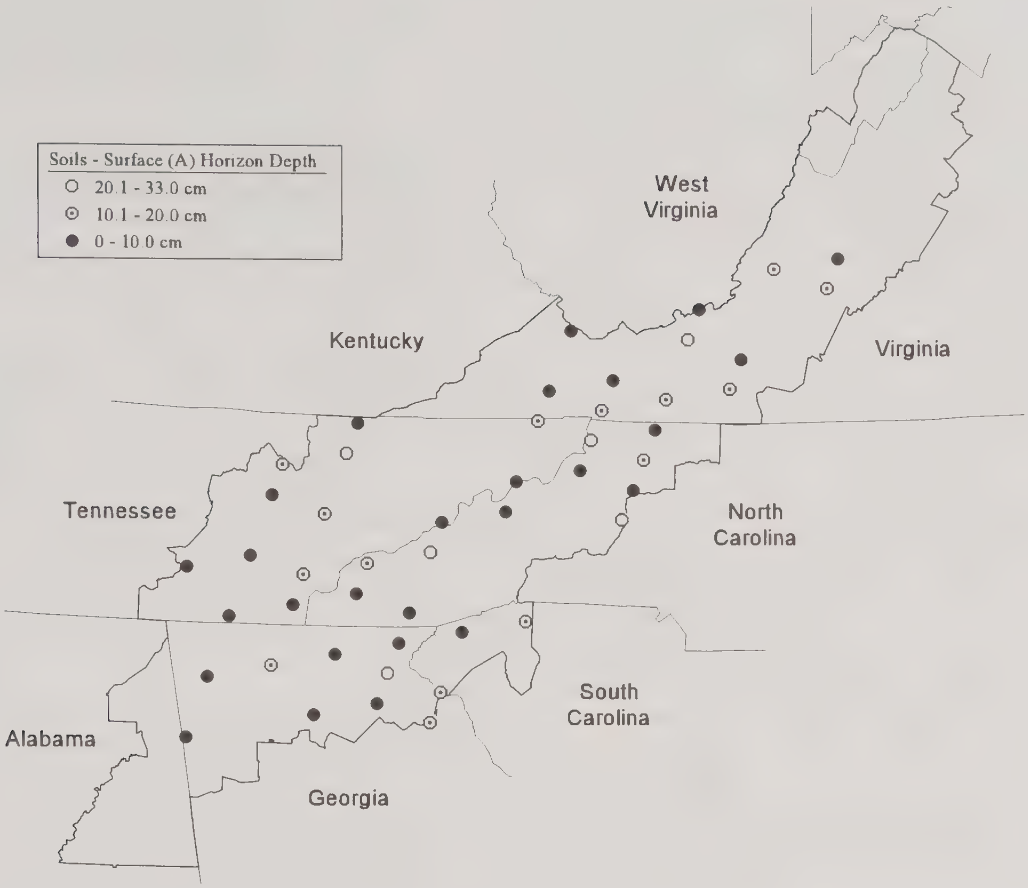

Figure 30—Spatial pattern of total surface horizon (A Horizon) depth in the Southern Appalachian region.

Some estimates have been made from soils data bases such as STATSGO although the reliability of these estimates is unknown. During the last half century soil organic matter levels have increased in many forested areas of the Eastern United States as forests recover from past exploitative use (such as clearing, cutting for charcoal, widespread grazing). Increases in soil organic matter levels result in increases in both aboveground and belowground biomass (Hudson 1995).

Soil fertility has been estimated in the Southern Appalachian region as the amount [kilograms per hectare (kg/ha)] of total organic carbon and total nitrogen in both the O horizon and the A horizon, the percent organic matter in the O horizon, and the Bray I phosphorus and the exchangeable calcium, magnesium, and potassium in the A horizon (Hudson 1997). Samples are collected from the A horizon and from the 10-cm (4 inches) layer below the A horizon. The relative amounts of total nitrogen from the A horizon and total carbon from the O and A horizons from plots within the Southern Appalachian region are examined in this report.

The nitrogen concentration in the A horizon was relatively low throughout the Southern Appalachian region. Most plots had concentrations of N <1,000 kg/ha, with only a few plots exceeding 2,000 kg/ha (fig. 31). No spatial pattern was apparent in nitrogen concentrations. The total carbon concentration in the O and A horizons was also relatively low throughout the Southern Appalachian region (fig. 32). Almost all the plots sampled had total carbon concentrations <110,000 kg/ha; only one plot had total carbon concentration exceeding 185,000 kg/ha.

No general conclusions can be drawn about the relative concentrations of nitrogen and carbon in the Southern Appalachian region or the spatial pattern of these concentrations. Further analysis must examine the species found on the plot and additional soil characteristics before total fertility of these soils can be evaluated. These measurements do serve as a reference for future evaluations of soil fertility factors.

Soil Acidity

The degree of soil acidity (typically estimated by pH) is a strong indicator of nutrient availability and biological function. Furthermore, scientists are concerned that forest soils in the Eastern United States are becoming more acid as a result of acid precipitation. Some maintain that soils are becoming more acid whereas others disagree stressing the considerable buffering capacity of forest soils. Soils data collected as part of FHM in the Southern Appalachian region probably represent the first probabilistic estimate of

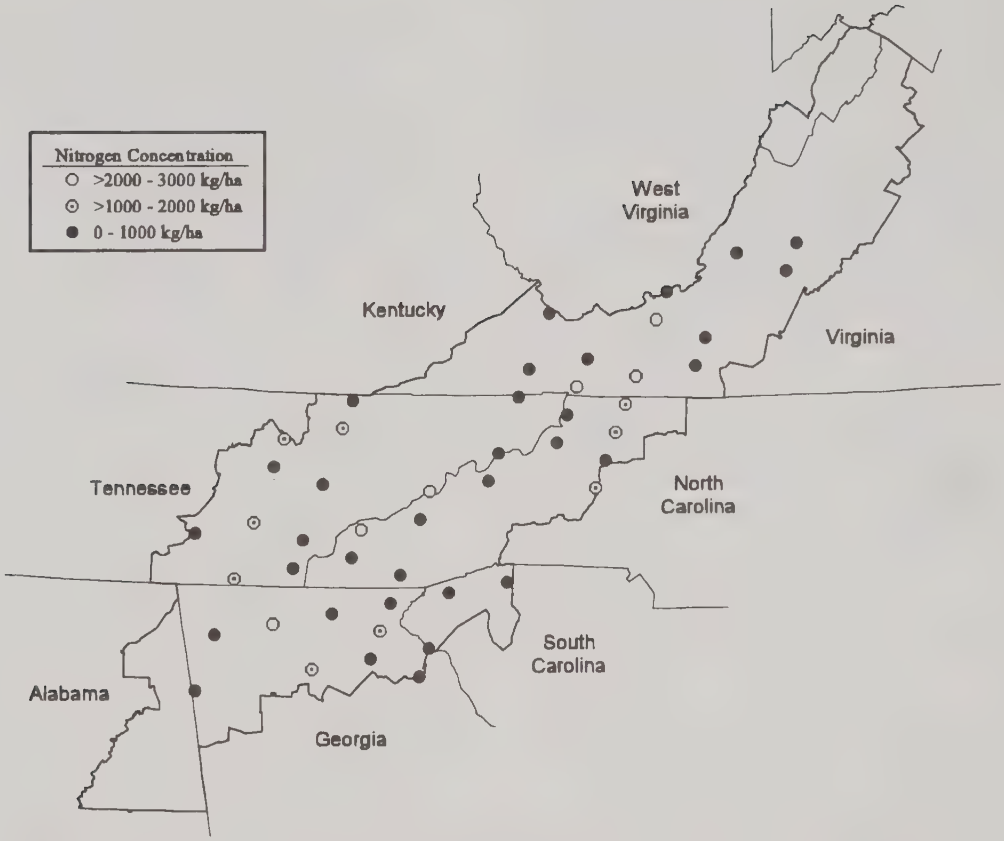

Figure 31—Spatial pattern of nitrogen concentration in mineral soil in the Southern Appalachian region.

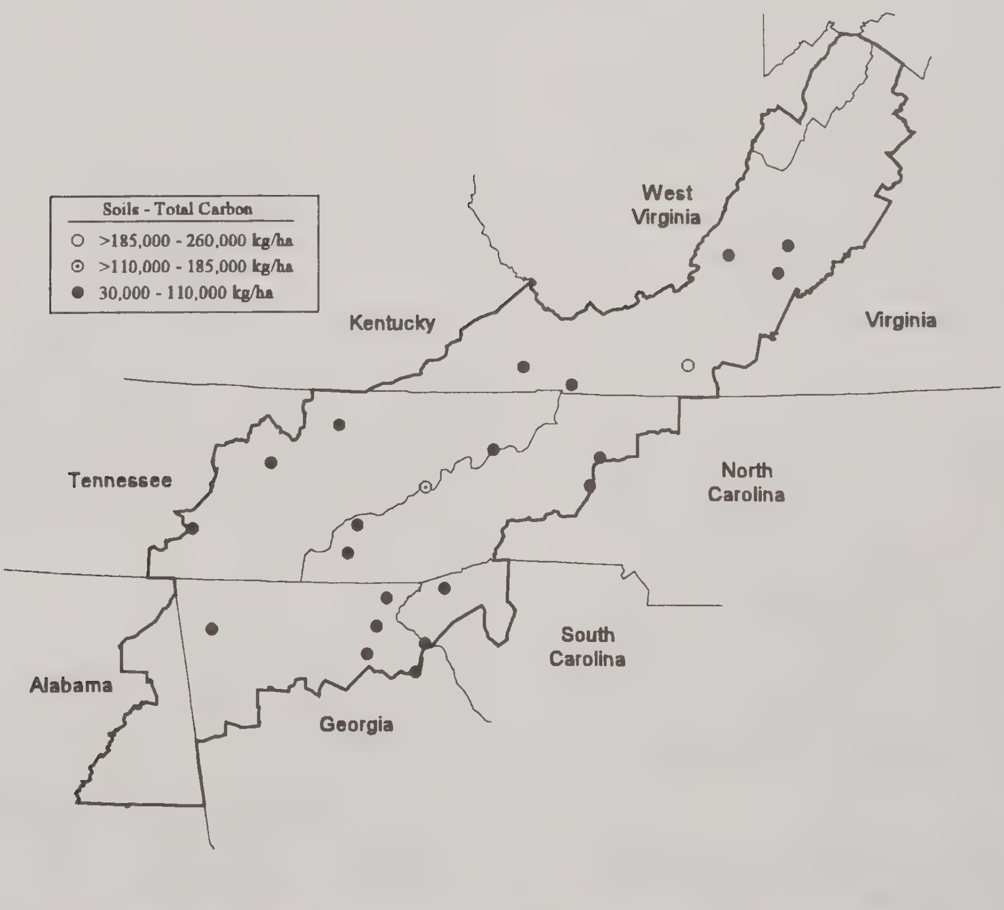

Figure 32—Spatial pattern of total carbon concentration in the O and A horizon soil in the Southern Appalachian region.

soil acidity over a geographic area. Soil acidification is a potential concern throughout the Southern Appalachian region, but FHM soils data represent only a portion of the region.

Some soils in the region have high levels of acidity in the mineral surface layer; for example, pH readings as low as 3.8 were encountered. No spatial pattern appears in pH levels. Making a prognosis concerning spatial trends is not feasible.

The FHM data are based on probabilistic sampling and are of high quality. Therefore, they provide an accurate snapshot of current conditions in a part of the Southern Appalachian region. Future research should assess the nature of areas with very low pH. Because soil acidification is both a scientific and societal concern, acidity levels of Southern Appalachian soils should be monitored using probabilistic sampling.

Wildlife Habitat

Estimates of the abundance and health of wildlife populations can be based on vegetation conditions present including species composition, distribution, and structure (Gast and others 1991). Vegetation is a reflection of environmental conditions, primarily moisture gradients and biotic factors that affect plant species and their capability to survive and establish communities. In the absence of human influences, vegetation communities were generally affected by soils, microtopography within moisture gradients, fire sequences, and perturbations caused by endemic levels of insects and diseases.

Wildlife populations, insects, and disease all respond to changes in vegetation conditions. The most responsive wildlife populations are those associated with early and midseral plant communities. Other species highly responsive to changes in forest composition or spatial organization of plant communities are cavity-dependent wildlife and large predators such as bears, cougars, and wolves.

Significant changes in composition and structure of western forests can occur in forest types where fire exclusion and selective harvest result in a mixture of shade-tolerant conifer species and over-stocked stands. Repeated insect defoliation of shade-tolerant species in these plant communities has resulted in reduced thermal cover for big game. In addition, accumulated coarse woody debris, particularly lodgepole, can force species such as elk to use other habitats. Returning to more natural fire cycles would also improve the availability and quality of large herbivore forage. Standing dead snags, standing future snags, old-growth stands, good canopy condition, low, coarse, woody debris, and species composition in the understory that provides suitable forage for herbivores will generally provide habitat for diverse faunal species.

Data from FHM plots that could be used to evaluate habitat suitability of forest stands for wildlife habitat follow.[9] The 1996 FHM field guide (Conkling and Tallent-Halsell 1996) provides details on specific information available in each FHM data category.

Wildlife data	FHM strata	FHM data category
Habitat	Plot level	Boundary data Site index Forest type Basal area/acre Stand origin Stand size Stand age Seedling/acre Quadratic mean diameter Number of species/condition class
Habitat	Tree level	Live tree snags Number/d.b.h./wood density Standing dead tree snags Number/d.b.h./wood density/number of years dead Down dead trees Number/d.b.h./wood density/number of years down
Food source	Tree level	Species type Nut/fleshy-fruit/other D.B.H.

Summary and Conclusions

To quantify changes in the sustainability of United States forests, repeated observations of individual trees and tree populations are necessary. Data from the FHM fixed-area field plots meet these requirements. The FHM national field plot network is systematic and is designed to allow probabilistic estimates. Complete sampling coverage of all United States forests would increase the representativeness and precision of quantitative estimates based on FHM data.

Data about the urban/wildland interface indicate areas of the country where expansion of urban conditions into forests increases the probability of forest fragmentation and other risks, such as increased human-caused fires. These areas are located in western portions of the Rocky Mountains in Colorado, the northern Sierra Nevada and Coast Range in California, and diverse forested areas of Alabama, Georgia, West Virginia, and Virginia.

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[9] Personal communication. 1996. William Burkman, USDA Forest Service, Southern Research Station, P.O. Box 2680, Asheville, NC 28802.

Conversely, relatively large, unbroken areas of Maine, Vermont, New Hampshire, and Connecticut are entirely forested.

In general, we conclude that tree crown dieback—an indicator of the initial stages of tree decline—is relatively low throughout the 18 States examined in this report. Relatively high dieback has occurred in localized areas, such as southwestern Maine; but, generally, dieback findings do not indicate early decline in the region. The evaluations do indicate that dieback is a more serious condition for hardwood species than for softwood species.

Data do not indicate any relatively high regional incidence of tree damage from biotic or abiotic agents although low levels of tree damage are common, particularly in the Northern States. Similarly, relatively high or moderate regional tree damage severity is not indicated. We conclude that although finding some damaged trees on many plots is common, the damages are few and not severe. Like dieback, hardwoods are more often affected than softwoods.

Air pollution is an apparent threat to forest health in many areas of the Northeast, Southeast, and Great Lakes States. Ozone is a potential problem in localized areas of the Great Lakes and in southern New England. Ozone data from the Southern States were not obtained for this report. However, lichen community analysis from the Southern Appalachian, Piedmont, and Coastal regions indicates regional problems with air quality, particularly in Virginia, the Piedmont, Appalachian foothill areas, southern New England, and the mid-Atlantic States. In general, we conclude that air pollution is a potential threat to many forest stands in the eastern FHM States. The pH of mineral soil in the Southern Appalachians serves as an important baseline for reference to any future changes.

The diversity of plant species, both vascular plants and nonvascular species such as lichens, varies greatly even within a relatively small area like the Southern Appalachian region. In general, lichen species richness is greater in some mountainous areas with relatively clean air. The data collected by the FHM program provide important baseline conditions for future evaluations and identify areas with relatively low species diversity.

The susceptibility of stands in the southern forests to SPB appears to be highest in south-central Alabama and lowest in Georgia and Virginia. In general, the States showing a high degree of SPB risk were also States with a relatively large acreage affected by SPB in the past. Similarly, the many oak stands in the Southern Appalachian region on both mesic and xeric sites have a high potential of changing to another dominant forest type once the oak overstory is removed.

In the Southern Appalachian region, the evaluation of soil factors, such as erosion, fertility, and carbon pools, indicates many sites have thin O and A horizon thicknesses. These sites are relatively susceptible to disturbance and exposure of mineral soil with subsequent increases in erosion rates. The analysis of nitrogen and carbon will provide important baseline data to evaluate any future changes.

The current implementation of the FHM program in 18 States provides insight into the health of forests in the United States. The overstory and understory trees and the soils in which they grow are the foundation of the forest ecosystem. The health of these trees, based on crown and damage evaluations, is good throughout most of the areas monitored. Within specific tree species, health problems do arise, especially those associated with native insects and diseases such as SPB, dwarf mistletoes, and fusiform rust. Exotic insects, diseases, and plants are a growing threat to many forest species and ecosystems, and urban expansion into forested areas has the potential to fragment forest ecosystems, introduce exotic species into forests, and increase problems with fire ignition and control.

The monitoring data collected in the FHM program compares well with the information needs defined in the Santiago Declaration. Many, if not all, of the current forest health issues addressed in this report can be related directly to the criteria and indicators in the Santiago Declaration. Additional forest health issues, such as productivity, can be addressed in future FHM reports by combining FHM and FIA data. Other forest health issues, such as forest contribution to carbon cycles, competition from exotics, fragmentation of forest types, and some biological indicators of key processes can be addressed in future FHM reports with the addition of new plot indicators, remote sensing, and new analytical techniques.

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A few individuals were equally important in many aspects of the report: Chuck Liff—summation of diverse FHM data; Elizabeth Eastman and Casson Stallings—formatting of data and development of ArcView maps of spatial distribution; Robert Mangold—numerous reviews and constructive input; and Barbara Conkling—numerous hours editing, developing tables, and producing report.

Literature Cited

Anon. 1995. Sustaining the World's forests: the Santiago agreement. Journal of Forestry. 93: 18–21.

Bailey, R.G. 1995. Description of the ecoregions of the United States. 2d ed., rev. and expanded. Misc. Publ. 1391. Washington, DC: U.S. Department of Agriculture. 108 p. [With separate map at 1:7,500,000].

Bechtold, W.; LaBau, V.J.; McLain, W. [and others]. 1995. Forest mensuration. 1995 version. In: Conkling, B.L.; Tallent-Halsell, N.G., eds. Forest health monitoring field methods guide. EPA/620/R-94/027. Washington, DC: U.S. Environmental Protection Agency. 371 p. Chapter 1.

Bennett, W.H. 1965. Silvicultural controls of forest insects. In: Insects in southern forests: Proceedings, 14th annual forestry symposium; [Date unknown]; Baton Rouge, LA. Baton Rouge, LA: Louisiana State University Press: 51–63.

Burkman, W.; Schomaker, M.; Stolte, K.W. [and others]. 1995. Crown condition classification. 1995 version. In: Conkling, B.L.; Tallent-Halsell, N.G., eds. Forest health monitoring field methods guide. EPA/620/R-94/027. Washington, DC: U.S. Environmental Protection Agency. 371 p. Chapter 2.

Carvell, K.L.; Tryon, E.H. 1961. The effect of environmental factors on the abundance of oak regeneration beneath mature oak stands. Forest Science. 7: 98–105.

Clark, F.B. 1993. An historical perspective of oak regeneration. In: Loftis, David; McGee, Charles E., eds. Oak regeneration: serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 3–13.

Clark, F.B.; Watt, R.F. 1971. Silvicultural methods for regenerating oaks. In: Proceedings of the oak symposium; [Date unknown]; Morgantown, WV; Upper Darby, PA: U.S. Department of Agriculture, Forest Service: 33–43.

Conkling, B.L.; Tallent-Halsell, N.G., eds. 1996. Forest health monitoring field methods guide. 1996 version. EPA/620/R-94/027. Washington, DC: U.S. Environmental Protection Agency. 381 p.

Crow, T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*) - a review. Forest Science. 34: 19–40.

Eyre, F.H., ed. 1980. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters. 148 p.

Forest Health Monitoring. 1994a. Forest health monitoring 1992 annual statistical summary. EPA/620/R-94/010. Washington, DC: U.S. Environmental Protection Agency. 41 p.

Forest Health Monitoring. 1994b. Forest health monitoring: a national strategic plan. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region. 13 p.

Forest Pest Management. 1995. Forest insect and disease conditions in the United States 1994. Washington, DC: U.S. Department of Agriculture, Forest Service. 74 p.

Gast, W.R.; Scott, D.W.; Schmitt, C. [and others]. 1991. Blue Mountains forest health report, new perspectives in forest health. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 320 p.

Hoffard, W.H.; Marx, D.H.; Brown, H.D. 1995. The health of southern forests. R-8 PR 27. Atlanta: U.S. Department of Agriculture, Southern Region, Forest Health. 36 p.

Houston, D.R. 1981. Stress triggered tree diseases, the diebacks and declines. NE-IF-41-81. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p.

Hudson, B.D. 1995. Reassessment of Polynov's ion mobility series. Soil Science Society of America Journal. 59: 1101–1103.

Hudson, B.D. 1997. Soil measurement and sampling. In: Forest health monitoring 1997 field methods guide. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, National Forest Health Monitoring Program. 448 p. Chapter 8.

Innes, J.L. 1993. Forest health. Its assessment and status. Wallingford, United Kingdom: CAB International. 677 p.

Kellison, R.C. 1993. Oak regeneration-where do we go from here? In: Loftis, David; McGee, Charles E., eds. Oak regeneration: serious problems practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 308–315.

Kolb, T.E.; Wagner, M.R.; Covington, W.W. 1994. Forest health from different perspectives. [Place of publication unknown]: [Publisher unknown]. 13 p.

Ku, T.T.; Sweeney, J.M.; Shelburne, V.B. 1980. Site and stand conditions associated with southern pine beetle outbreaks in Arkansas—a hazard rating system. Southern Journal of Applied Forestry. 4(2): 103–106.

Loftis, D.L. 1993. Regenerating northern red oak on high-quality sites in the Southern Appalachians. In: Loftis, David; McGee, Charles E., eds. Oak regeneration: serious problems practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 202–210.

Lorio, P.L., Jr. 1981. Rating stands for susceptibility to SPB. In: Thatcher, R.C.; Searcy, J.L.; Coster, J.E.; Hertel, G.D., eds. The southern pine beetle. Tech. Bull. 1631. [Place of publication unknown]: U.S. Department of Agriculture, Forest Service. 267 p.

Lorio, P.L., Jr.; Hodges, J.D. 1974. Host and site factors in southern pine beetle infestations. In: Payne, T.L.; Coulson, R.L.; Thatcher, R.C., eds. Southern pine beetle symposium; 1974 March 7–8; College Station, TX. [Place of publication unknown]: [Publisher unknown]: 32–34.

Lund, H.G.; Rudis, V.A.; Stolte, K.W. [In press]. Plots, pixels, and partnerships—prospects for mapping, monitoring and modeling biodiversity. In: SI/MAB. Proceedings of measuring and monitoring forest biological diversity, an international symposium; 1995 May 23–25; Washington, DC. [Publisher unknown]. 19 p.

MacCleery, D.W. 1992. American forests: a history of resiliency and recovery. FS-540. Washington, DC: U.S. Department of Agriculture, Forest Service. 58 p.

McGee, C.E. 1967. Regeneration in Southern Appalachian oak stands. Res. Note SE-72. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 6 p.

Mielke, M.; Burkman, W.; Cox, S. [and others]. 1995. Damage and catastrophic mortality assessment. 1995 version. In: Conkling, B.L.; Tallent-Halsell, N.G., eds. Forest health monitoring field methods guide. EPA/620/R-94/027. Washington, DC: U.S. Environmental Protection Agency. 371 p. Chapter 3.

Miller, P.R. 1992. Mixed conifer forests of the San Bernadino Mountains, California. In: Olson, R.K.; Binkley, D.; Böhm, M., eds. The responses of western forests to air pollution. Ecological Studies. Vol. 97. New York: Springer-Verlag: 461–497.

Olson, R.K.; Binkley, D.; Böhm, M., eds. 1992. The responses of western forests to air pollution. Ecological Studies. Vol. 97. New York: Springer-Verlag. 532 p.

Payne, T.L. 1981. Life history and habits. In: Thatcher, R.C.; Searcy, J.L.; Coster, J.E.; Hertel, G.D., eds. The southern pine beetle. Tech. Bull. 1631. [Place of publication unknown]: U.S. Department of Agriculture, Forest Service. 267 p.

Rapport, D.J.; Reigier, H.A.; Hutchinson, T.C. 1985. Ecosystem behavior under stress. American Naturalist. 125: 617–640.

Ricklefs, R.E. 1979. Ecology. 2d ed. New York: Chiron Press, Inc. 966 p.

Shadwick, D.D.; Smith, L.A. 1994. Selected air quality and deposition data summaries. In: Forest health monitoring. Forest health monitoring 1991 statistical summary. EPA/620/R-94/028. Washington, DC: U.S. Environmental Protection Agency. 178 p.

Smith, W.D.; Gumpertz, M.L.; Catts, G.C. 1996. An analysis of the precision of change estimation of four alternative sampling designs for forest health monitoring. Forest Health Monitoring Tech. Rep. Series. Research Triangle Park, NC: Forest Health Monitoring National Office. 24 p.

Smith, W.H. 1981. Air pollution and forests, interactions between air contaminants and forest ecosystems. In: DeSanto, R.S., ed. Springer series on environmental management. New York: Springer-Verlag. 379 p.

Southern Appalachian Man and the Biosphere (SAMAB). 1996a. The Southern Appalachian assessment atmospheric technical report. Report 3 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region. 83 p.

Southern Appalachian Man and the Biosphere (SAMAB). 1996b. The Southern Appalachian assessment terrestrial technical report. Report 5 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region. 286 p.

Stapanian, M.; Cline, S. 1995. Vegetation structure. 1995 version. In: Conkling, B.L.; Tallent-Halsell, N.G., eds. Forest health monitoring field methods guide. EPA/620/R-94/027. Washington, DC: U.S. Environmental Protection Agency. 371 p. Chapter 5.

Stephenson, S.L.; Ash, A.N.; Stauffer, D.F. 1993. Appalachian oak forests. In: Biodiversity in the Southeastern United States: upland terrestrial communities. New York: John Wiley: 255-337. Chapter 6.

Tallent-Halsell, N.G., ed. 1994. Forest health monitoring field methods guide. EPA/620/R-94/027. Washington, DC: U.S. Environmental Protection Agency. 245 p.

U.S. Department of Agriculture, Forest Service. 1995. Forest health highlights northeastern States. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 136 p.

Warrington, G.E.; Knapp, K.L.; Klock, G.O. [and others]. 1980. In: USDA Forest Service. An approach to water resources evaluation of non-point silvicultural sources (a procedural handbook). EPA-600/8-80-012. Athens, GA: U.S. Environmental Protection Agency, Environmental Research Laboratory. 81 p.

Wischmeier, W.H. 1976. Use and misuse of the universal soil loss equation. Journal of Soil & Water Conservation. 31: 5–9.

Wischmeier, W.H.; Smith, D.W. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. Agric. Handb. 282. Washington, DC: U.S. Department of Agriculture. [Number of pages unknown].

Appendix A—Insects and diseases affecting United States forests: agents and agent descriptions

Agent	Agent description
Root disease pathogens:	Native pathogenic organisms of conifers that cause mortality and growth loss and make trees more susceptible to effects of other biotic and abiotic agents.
South — Littleleaf disease *(Phytopthora cinnamomi)*	Tree species most affected by littleleaf disease are shortleaf and loblolly pines.
South and West — Annosus root disease (*Heterobasion annosum*)	Tree species most affected by Annosus root disease are all conifers, especially pines, hemlock, and true firs.
West — Armillaria root disease *(Armillaria mellea)*	Tree species most affected by Armillaria root disease are all conifers.
West — Laminated root rot *(Phellinus weirii)*	Tree species most affected by laminated root rot are Douglas-fir, true fir, mountain hemlock, and western redcedar.
Dwarf mistletoes (*Arceuthobium spp.*)	Native parasitic plants causing growth loss and mortality to western conifers. Sixteen species of dwarf mistletoe occur in the United States. Commercially important tree species affected include Douglas-fir, western hemlock, western larch, lodgepole pine, red fir, ponderosa pine, sugar pine, and white fir.
Fusiform rust (*Cronartium quercuum fusiforme*)	Native stem rust of southern pines. Causes stem and branch cankers that result in tree mortality. The most serious disease of southern pines. Tree species most affected are loblolly and slash pines.
White pine blister rust (*Cronartium ribicola*)	Introduced stem rust of eastern and western five-needle pines. Causes stem and branch cankers that result in tree mortality. Susceptible tree species include eastern and western white pine, sugar pine, whitebark pine, limber pine, and southwestern white pine.
Dogwood anthracnose (*Discula destructiva*)	A disease of unknown origin first reported in 1978. Leaf, twig, and branch infections lead to lethal stem infections. Dogwood anthracnose has spread widely in both the East and West as both eastern and western dogwood species are susceptible to infection.
Gypsy moth (*Porthetria dispar*)	Introduced defoliator of eastern hardwood forests. Now introduced in the West. Defoliation causes growth loss, decline, and mortality. Gypsy moth feeds on a wide range of tree species. Preferred hosts include oak, birch, sweetgum, aspen, willow, and American basswood.
Southern pine beetle (*Dendroctonus frontalis*)	Native bark beetle of southern pine forests. The most destructive insect of southern pine forests; infestations cause extensive mortality. Susceptible tree species include loblolly, slash, and shortleaf pines.
Mountain pine beetle (*Dendroctonus ponderosae*)	Native bark beetle of western ponderosa and lodgepole pine forests. Infestations cause extensive mortality.
Spruce budworm (*Choristoneura fumiferana*)	Native defoliator of northeastern and north central spruce-fir forests. Causes growth loss and mortality.
Western spruce budworm (*Choristoneura occidentalis*)	Native defoliator of western Douglas-fir, spruce, and fir forests. Causes growth loss and mortality.

Appendix B—Index of cited common and scientific names

Tree species	Scientific name
American basswood	*Tilia americana* L.
American chestnut	*Castanea dentata* (Marsh.) Borkh.
Aspen	*Populus spp.*
Birch	*Betula spp.*
Black oak	*Quercus velutina* Lam.
Butternut	*Juglans cinerea* L.
Chestnut oak	*Quercus prinus* L.
Dogwood	*Cornus florida* L.
Douglas fir	*Pseudotsuga menziesii* Mirb. Franco
Eastern white pine	*Pinus strobus* L.
Fraser Fir	*Abies fraseri* (Pursh.) Poir.
Hemlock	*Tsuga sp.* (Endl.) Carr.
Limber pine	*Pinus flexilis* var. *reflexa* Engelm.
Loblolly pine	*Pinus taeda* L.
Lodgepole pine	*Pinus contorta* Dougl.
Northern red oak	*Quercus rubra* L.
Oak	*Quercus spp.*
Ponderosa pine	*Pinus ponderosa* Dougl. ex laws
Redcedar	*Juniperus spp.*
Red fir	*Abies magnifica* A. Murr.
Red spruce	*Picea rubens* Sarg.
Red maple	*Acer rubrum* L.
Shortleaf pine	*Pinus echinata* Mill.
Slash pine	*Pinus elliottii* Engelm.
Sugar maple	*Acer saccharum* Marsh.
Sugar pine	*Pinus lambertiana* Dougl.
Sweetgum	*Liquidambar styraciflua* L.
Tulip poplar	*Liriodendron tuplipifera* L.
Western larch	*Larix occidentalis* Nutt.
White ash	*Fraxinus americana* L.
White fir	*Abies concolor* (Gord. & Glend.) Lindl.
Whitebark pine	*Pinus albicaulis* Englem.
Willow	*Salix spp.*

Appendix B—Index of cited common and scientific names (continued)

Pests	Scientific Name
Annosus root disease	*Heterobasion annosum*
Armillaria root disease	*Armillaria mellua* Vahl.
Beech bark disease	*Nectria coccinea var. faginata* Loh., Wats., & Ay
Butternut canker	*Sirococcus clavigignenti-juglandacearam* N. Blair, Kostichka & Kuntz
Chestnut blight	*Cryphonectrica parasitica* Murr. Barr
Dogwood Anthracnose	*Discula destructiva Redin* sp. Nov.
Dutch elm disease	*Ceratocystis ulmi* Buism. Nannf.
Dwarf mistletoes	*Arceuthobium spp.*
Fusiform rust	*Cronartium quercuum* (Berk.) Miy. Ex Shiari f. sp. *fusiforme*
Gypsy moth	*Lymantria dispar* Linnaeus
Hemlock aldelgid	*Adelges tsugae* Annand
Japanese honeysuckle	*Lonicera japonica* Thunb.
Laminated root rot	*Phellinus weirii*
Littleleaf disease	*Phytopthora cinnamomi* Rands
Mountain pine beetle	*Dendroctonus ponderosae* Hopkins
Southern pine beetle	*Dendroctonus frontalis* Zimmermann
Spruce budworm	*Choristoneura fumiferana* (Clemens)
Western spruce budworm	*Choristoneura occidentalis* Freeman
White pine blister rust	*Cronartium ribicola* Fisch.

Stolte, Kenneth W. 1997. 1996 national technical report on forest health. Admin. Rep. FS-605. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 47 p.

Forest Health Monitoring (FHM) is a national program designed to determine the status, changes, and trends in indicators of forest condition on an annual basis. The FHM program uses data from ground plots and surveys, aerial surveys, and other biotic data sources and develops analytical approaches to address forest health issues that affect the sustainability of forest ecosystems. This report focuses on 18 States that have ground plots. Six forest health issues were identified by the FHM program in 1996 to evaluate forest health; forest ecosystem fragmentation, forest vitality, key ecosystem processes, plant biodiversity, soil conservation, and wildlife habitat.

Keywords: Damage, exotic vegetation, forest health, indicators, insects and disease, monitoring, sustainability criteria.

The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.